CARBON-DIOXIDE EMISSIONS FROM TRANSPORT IN IEA COUNTRIES: RECENT LESSONS AND LONG-TERM CHALLENGES

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International Energy Agency

February 1999

[1] Opinions those of the authors and not necessarily those of the IEA, KFB, or other organisations that sponsored the original work reviewed in this paper.

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FOREWORD AND ACKNOWLEDGEMENTS

In 1993, the Swedish Council for Transport and Communications Research (KFB) provided the Energy Analysis Program of the Lawrence Berkeley National Laboratory with a three year grant to integrate many projects and ideas that had been developed under the rubric “The future of the Automobile in an Environmentally Constrained World”, a project also supported by AB Volvo through grants to LBNL and to the University of California. Professors Elisabeth Deakin of the Institute for Urban and Regional Development, UC Berkeley, and Daniel Sperling of the Center for Transportation ‘Studies, UC Davis, were co-leaders of the initial effort with Dr. Lee Schipper.

In 1995 Dr. Schipper became a visiting Senior Scientist at the International Energy Agency, where this work continued with the kind support of the IEA. The initial review of the work sponsored by KFB was prepared in 1997 and finalised with this version. Parts of this paper have appeared in conference proceedings.

Dr Lorna Greening (now a consultant), Mr Roger Gorham (now with the World Bank), and Ms. Maria Josefina Figueroa (now Risoe National Laboratory, Denmark) were members of the core LBNL team and contributed to an earlier summary of KFB work. Prof. Elisabeth Deakin of the University of California, Berkeley and Daniel Sperling of the University of California, Davis, helped lead the initial efforts upon which this work was built. We thank Lorna Greening, Roger Gorham, and Maria Josefina Figueroa, all formerly of Lawrence Berkeley Laboratory, who contributed to an earlier version of this paper. Other participants in this program included Dr. Ruth Steiner, now at Univ. of Florida; Dr. Olof Johansson, Univ. of Gothenburg, Gunnar Eriksson, NORDPLAN (Stockholm, now at the Ministry of Transport), and former LBL staff W. B. Davis, Lynn Scholl, Kari Dolan, and UC Davis graduate student Molly Espey. Karen H. Olson provided invaluable editing assistance, and Cynthie P. Almazol and Marta P. Khrushch also helped with the preparation of the original manuscript.

This work was supported by the Swedish Board for Communications and Transport Research, in a three year grant to the Lawrence Berkeley National Laboratory (1993-1995). The financial support of Volvo AB, General Motors, Ford Motor Company, Chrysler Corporation, Exxon Co. International, Shell Oil, Shell International Petroleum Company, and British Petroleum, all directed at LBNL or the University of California, were crucial to supporting the many students who contributed to this work. We acknowledge the support of the International Energy Agency, which encouraged this work to continue.

Jan Parmeby was the original manager of this project. Since 1994 it was been managed by Christine Wallgren and then Claes Unge, whose assistance and patience we gratefully acknowledge.

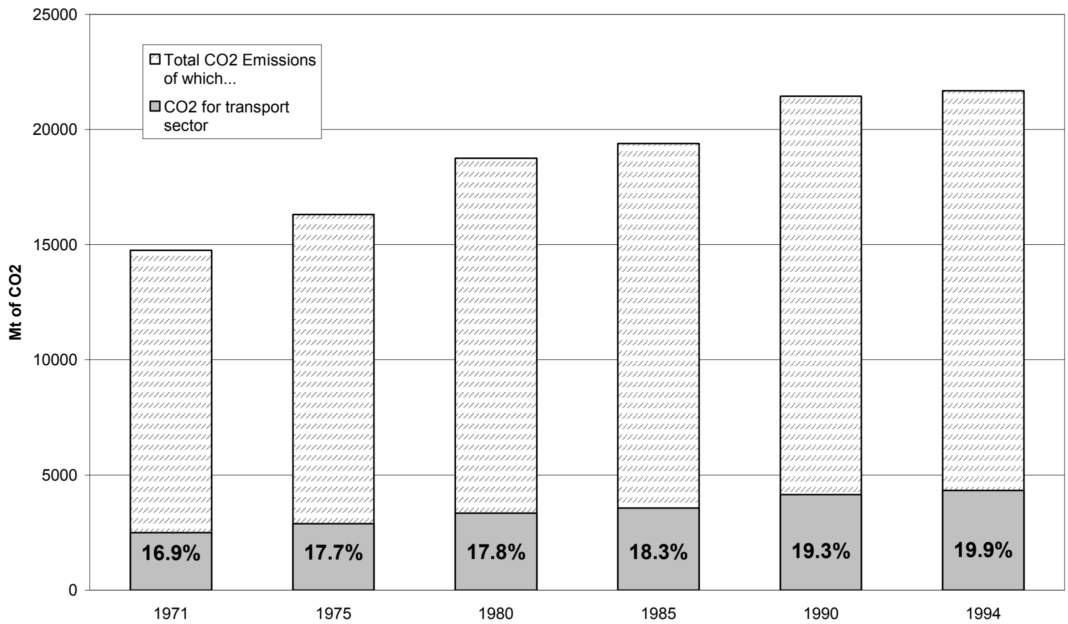
I. INTRODUCTION

1. The CO_2 Problem: The Policy Imperative after Kyoto.

In December 1997, leaders of the world's governments met in Kyoto, Japan, to discuss a protocol for reducing greenhouse gas emissions from number of anthropogenic sources, particularly carbon emission from the use of fossil fuels. While the details of each country's pledges, commitments, or expectations vary greatly among countries, all parties were aware of the key role transportation played in the rise of emissions from fossil fuels.

Figure 1 shows the role of the transportation sector as a source of CO_2 emissions from energy use. This role had not gone unnoticed before Kyoto. In this review we highlight the key trends in transportation and carbon emissions that make restraint of those emissions so enigmatic for policy-makers.

Figure 1: World CO2 Emissions
Total and Transport Sector



source: IEA

2. Why The Focus On Transportation?

Transportation has long been associated with environmental and other problems beyond CO_2. These include safety, air, water, and noise pollution, competition for urban space, balance of payments problems and risks associated with importing oil as the main transport fuels[2]. While few doubts that transportation returns a huge surplus to every economy, there are segments of transport activity where real social costs are greater than the benefits accruing to drivers or shippers. This was emphasised in a study organised by the European Conference of Ministers of Transport (ECMT, 1998). That group concluded "Significant welfare gains could be realised through an adjustment of charges and taxes to provide incentives for reducing the external costs of transport". They estimated that current welfare

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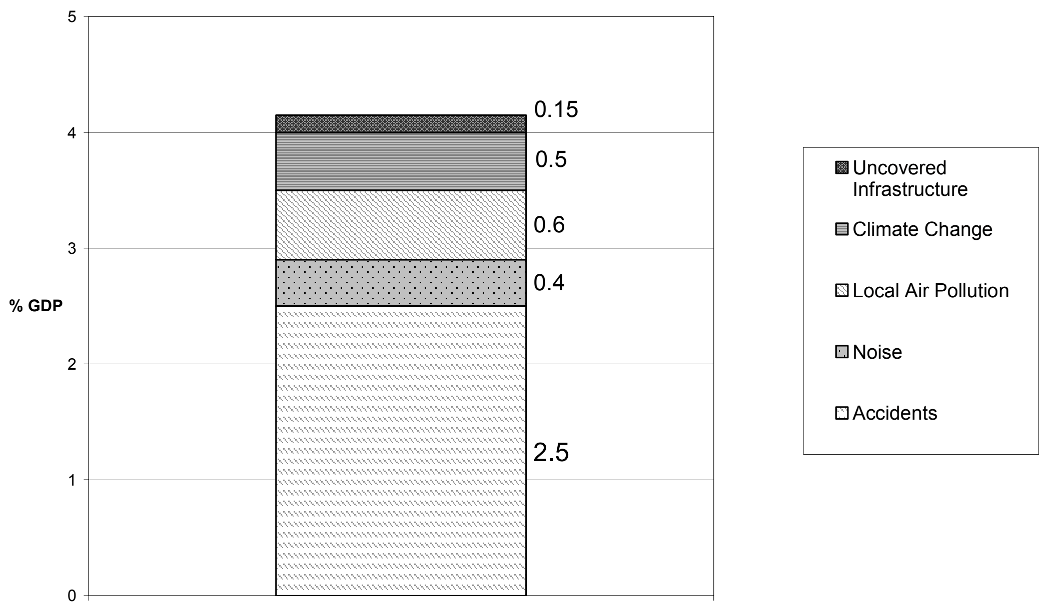
[2] See Kaageson, 1993; COWI, 1993; OECD, 1995; CEC, 1995a; COWI, 1995a, 1995b; Dept. of Transport, 1996; Pearce et al., 1996; Det Oekonomiske Raad, 1996, Delucchi, 1997, ECMT 1998.

losses amount to “several points of GDP”. This is shown in Figure 2. Internalisation of those costs, through both direct charging and some regulations, could have a significant restraining impact on the system in the long run.

Figure 2: Average Estimates of Total External Costs of Road and Rail Transport



Source: ECMT, 1997

In this context, the emissions of greenhouse gases have not been ignored in major national environmental strategy documents[3]. Whatever the “real” external costs of each mode, studies suggest that the values attached to the externality for GHG emissions alone tend to be low compared to those associated with other problems. This suggests that CO_2 by itself may not ”felt” as a strong stimulus for change, but that changes to deal with the other problems may affect traffic, and therefore CO_2 emissions perhaps even profoundly. The other externalities in transportation may be more serious than CO_2 in the short run. These threats, whether real or perceived, stimulation constituencies to press today for or accept imposition of “solutions”, by which technologies and policies could be brought to bear to reduce the problems.

CO_2 emissions, by contrast to other external effects, present no obvious problem for the present generations, particularly as there is some debate about timing and extent of damaged we face. Not surprisingly, there may be no strong forces to restrain emissions. Still, policy-makers from some spheres are under pressure from certain constituencies to affect transportation’s rising CO_2 emissions now. This review is about the challenge they face. We use international comparisons to highlight trends and differences, achievements and difficulties that underlie that challenge.

3. Quantitative aspects of CO_2 Emissions from Transportation

Figure 1 gave a global overview of the evolution of carbon emissions from transport sector. The transport sector’s share is significant. By 1995 transportation emissions had increased in both per capita terms or as a share of emissions in almost all countries, compared with 1980 or 1973.

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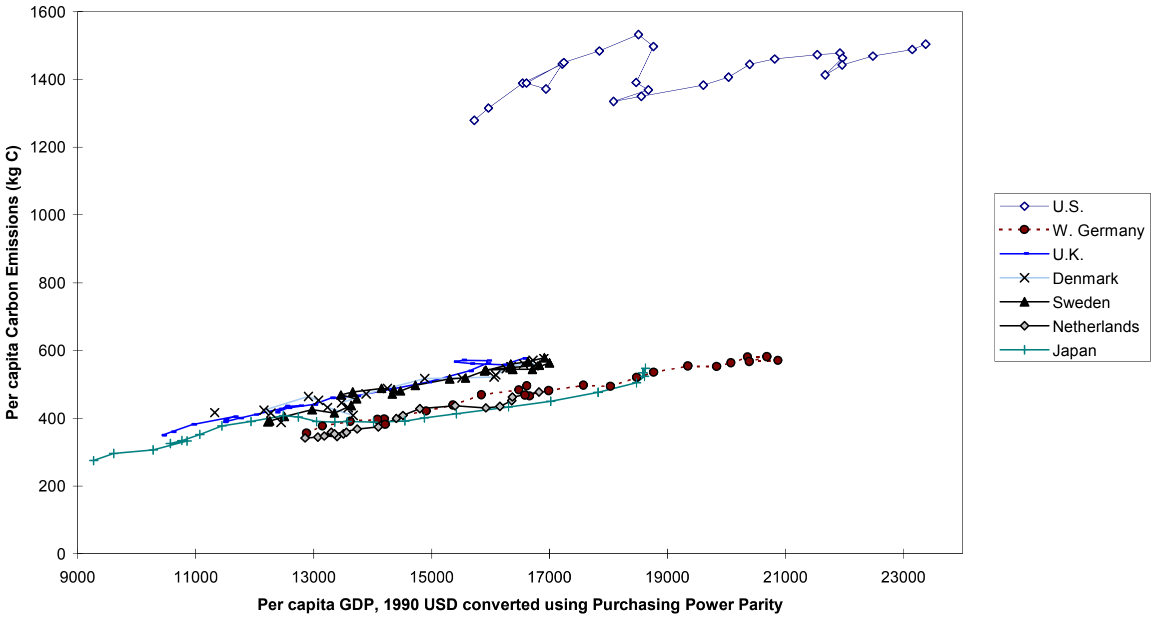
[3] (Houghton, 1994; CEC, 1995b; UM, 1991a; UM 1991b; VROM, 1996a, 1996b; KOMKOM, 1997; US NRC, 1997; Trafik Ministeriet, 1997).

Figure 3 shows how per capita emissions passenger and freight transport have risen with per capita GDP for the IEA member countries studied here plus Japan. While there are differences in the slope of the rise in emissions vs. income by country, and differences in the level at a given income, there is little sign of any break in the connection between increased income and increased emission. The only exception occurred in the U.S. occurred during a period of much higher fuel prices[4].

Figure 3: Per Capita GDP and Per Capita Carbon Emissions from Travel and Freight



Source: LBNL and IEA

On the surface, then, the coupling between per capita income and per capita emissions from transport appears strong if no other forces intervene. This seems to give a clear message: reducing or even restraining emissions from transportation may be difficult compared with other sectors. This is both a technical and a political issue. Confronting this issue depends on a good understanding of the forces driving energy use and emissions related to transportation. We focus on these for the remainder of this paper, returning briefly at the end to indicate what consequences the trends have for policies.

II. TRENDS IN TRANSPORTATION ACTIVITY

In the remaining sections we review the key transportation demands that are in turn derived for demands for personal access to people and services as well as manufacture and trade in goods, travel and freight respectively. After we review these demands and the energy uses associated with them, we will study how they interact.

1. Underlying Factors Affecting CO_2 Emissions for Travel and Freight: A Decomposition Approach

A framework is needed to understand factors affecting CO_2 emissions from transport and differences among countries[5]. Lawrence Berkeley National Laboratory has carried out an index decomposition of

[4] In Figure 3, emissions and per capita income for 1971 make up the left-most point in each curve, while 1995 values form the last point to the right. The apparent reversal in some years stems from recessions that lowered per capita GDP.

[5] Concerning decomposition in other sectors, see Schipper 1995; Schipper, Figueroa, Price, and Espey, 1993; Schipper,

the factors underlying changes in CO2 emissions from both freight and travel, as well as from other sectors[6].

All of these methods start from a basic formula (Schipper and Lilliu 1999). Consider that

$$\mathbf{G = A * S_{\mathit{i}} * I_{\mathit{i}} * F_{\mathit{i,j}}} \quad \mathbf{(1)}$$

where **G** is the greenhouse gas (carbon) emissions from, **A** is total travel activity, **S** is a vector of the modal shares I, and **I** is the modal energy intensity of each mode *i*. The last term $\mathbf{F}_{i,j}$ represents the sum of each of the fuels *j* in mode *i*, using standard IPCC coefficients to convert fuel (or electricity) used back to carbon emissions. Emissions from the electric power sector are allocated to end-use electricity (rail, tram etc.) at the countrywide average ratio of total sectoral emissions to electricity produced in the economy[7].

The modal energy intensity term itself is composed of several components[8]:

$$\mathbf{I_{\mathit{j}} = E_{\mathit{i}} * VC_{\mathit{i}} * CU_{\mathit{i}}} \quad \mathbf{(2)}$$

where E is technical efficiency, VC vehicle characteristics, and CU capacity utilisation for each mode *I*. Taking only E and VC yields what we call vehicle intensity, or fuel/kilometre.

Technical efficiency is the energy required to propel a vehicle of a given set of characteristics a given distance, and is affected by the motor, drive train, frictional terms (including drag), etc. For cars, characteristics could be represented by car power, and technical efficiency by energy use per km per unit of power. Capacity utilisation would be measured as the number of people per vehicle.

All three of these components share in determining how much energy is used to transport a person one kilometre by each mode:

Fuel choice affects efficiency because some fuels, particularly diesel, are combusted more efficiently in their respective engines than others. By contrast, LPG-based cars are usually more energy intensive then gasoline cars because the former are converted from the latter after production, not purpose-built.

- Driver behaviour and traffic affect technical performance.
- And larger, more powerful vehicles often stimulate drivers to make the vehicles perform, i.e., go faster.

Thus some terms in this decomposition that are nominally “technical” -- energy intensities -- actually have important behavioural components. Total travel and modal choice are obviously “behavioural” factors, too. The same is true for changes in power, or changes in traffic and driver behaviour, all of which affect how technology turns energy into mobility.

This relation illustrated by Equations 1 and 2 can be used to study changes in energy use or emissions over time, and the results expressed as indices marking the changes in each component. Many indices serve this purpose, Laspeyres indices are presented in Paragraph 4. They show, as we shall develop

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Steiner, Figueroa, and Dolan, 1993.

[6] See for example Schipper, Steiner, Duerr, An, and Stroem, 1992; Schipper et al., 1996; Scholl, Schipper and Kiang, 1996; Schipper, Scholl and Price, 1997.

[7] Net of power station own-use and transmission losses. More detailed analysis could explore the full fuel-cycle emissions from obtaining and refining the fuels, but the present analysis is limited to combustion.

[8] Real drive cycles and routing also influence modal energy intensity.

later, the impact of one factor alone on overall change[9].

Feedback between these components are important, but not major in the countries we have studied. Unquestionably lower driving costs per km, whether brought on by lower fuel prices or lower fuel intensities, encourage more driving. But the elasticities are only modest: 10% lower costs leads to somewhat more than 1% more driving in the U.S., to perhaps 2-3% more in Europe, with the average around 2-2.5% (Johansson and Schipper 1997). Lower costs of using cars discourage use of other modes, as can be seen by comparing relative fuel and transit costs and relative ridership in different cities in Europe. As fuel costs rise, transit ridership rises slightly, and vice versa. More subtle in nature is the impact of lower costs on technology: technology is boosting power at roughly constant fuel economy, rather than reducing fuel use at roughly constant power. These are all important feedbacks, but they do not invalidate our main conclusions on historical trends. As we have seen subsequently, however, policies that only aim at lowering fuel use and fuel costs will usually lead to less CO_2 restraint than policies that include elements that counter this trend by either raising fuel prices or raising other variable costs of transportation.

This approach is very useful for the policy analysis that was carried out in the previous chapters. For one thing, many policy elements focus on one of the components in Equations 1 or 2. Many successful packages address most or all of them. : Packages addressing all of the components in a concerted and coherent, self-consistent manner usually have a greater effect than the sum of the effects of policies addressing the elements separately. This is both because synergies among the policies can be more powerful than individual policies alone, and because the feedbacks noted above may act to offset hoped-for policy effects when key components are left out. In a historical perspective, analysis of past behaviour reveals which components have changed the most, perhaps (but not always) in response to policies, which are more rigid. For example, changing fuel prices, fuel economic regulations, and new technologies have had important impacts of fuel economy of cars, but little impact on the overall growth in car use with income. Judging from history which components of rising emissions may yield to different stimuli is an important part of the policy that each country we have studied must undergo.

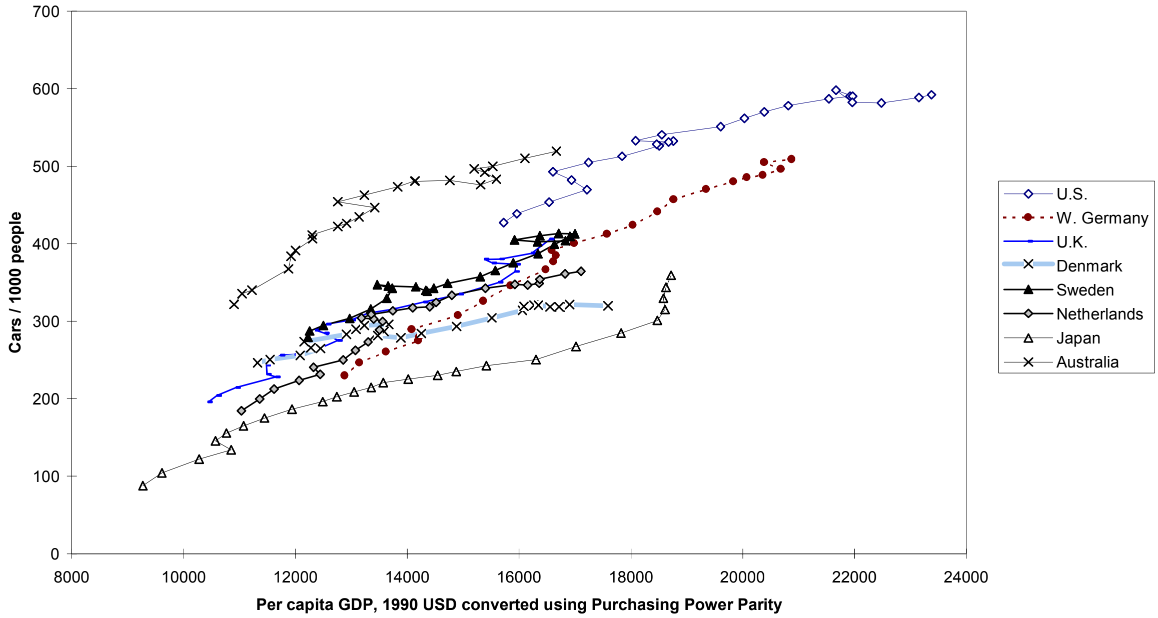
2. Transportation of people

Travel, or transportation of people, typically accounts for 60-70% of energy use and emissions from transportation. [10] Travel activity **A** is measured in passenger kilometres over each mode **S**i. The key component is automobile travel, and that is driven by automobile ownership (Figure 4). Ownership has risen with income or GDP per capita, although it is showing some saturation in the most motorised countries, as the figure clearly suggests. Distance travelled per vehicle (vehicle-km, or v-km) is rising slowly with income too. However, distance travelled per capita (Figure 5) is rising more rapidly, principally because of increasing car ownership rather than the slow rise in distance travelled per vehicle.

[9] A case for using Laspeyres indices is their simplicity. However, note that Laspeyres indices often leave large residuals.

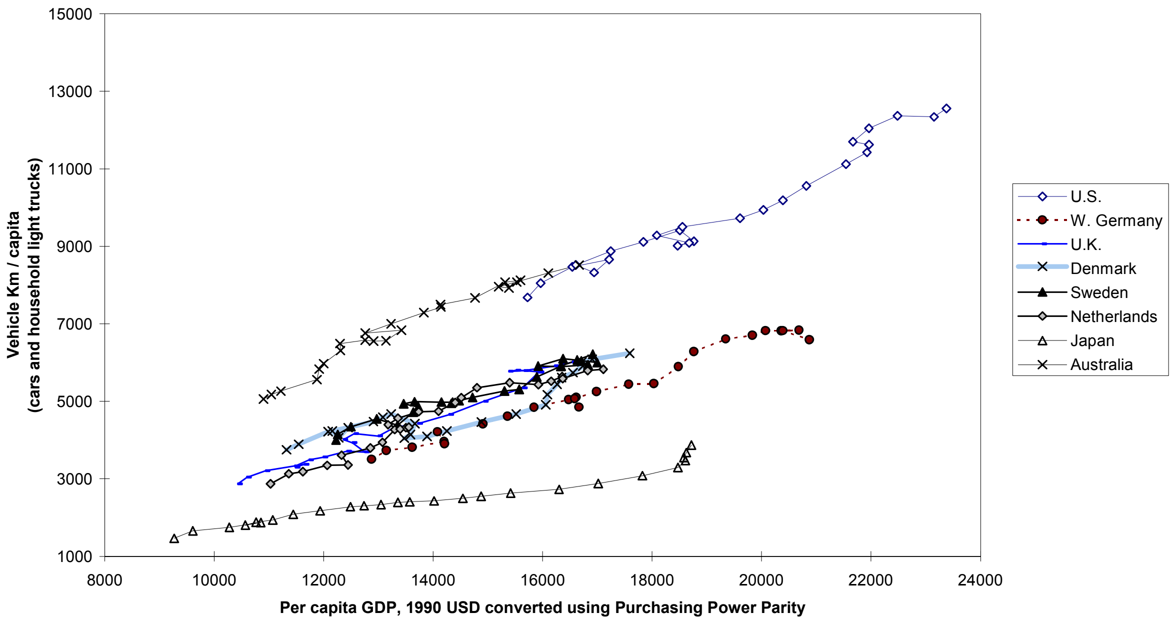
[10] Behind figures for vehicle, passenger, and freight movements, and energy use lie careful tabulations of gasoline and diesel fuel (also LPG and natural gas) for each mode of road traffic, a split of energy use for domestic rail and water traffic into passenger and freight shares, and determination of the domestic share of fuel used for air travel. Energy uses excluded are military vehicles, international marine and air fuel, civil aviation, and some miscellaneous vehicles. See Schipper et al. (1992) for the first decomposition study, Schipper (1995) for a review of trends in automobile energy use, Scholl, Schipper and Kiang (1996) for the analysis of CO_2 from travel. Kiang and Schipper (1996) for the analysis of Japan, Schipper, Scholl and Price (1997) for the analysis of freight or Schipper, Meyers et al. (1992) for information on how these splits (and original data) were obtained. Data for Canada, the Netherlands, and Australia were gathered during IEA studies of these countries. Many data used in this study are published by the Oak Ridge Nat.l Lab. in the “Energy and Transportation Handbook”.

Figure 4: Car Ownership and Per Capita Income 1970-1995



Source: LBNL and IEA

Figure 5: Car Driving and Per Capita Income 1970-1995



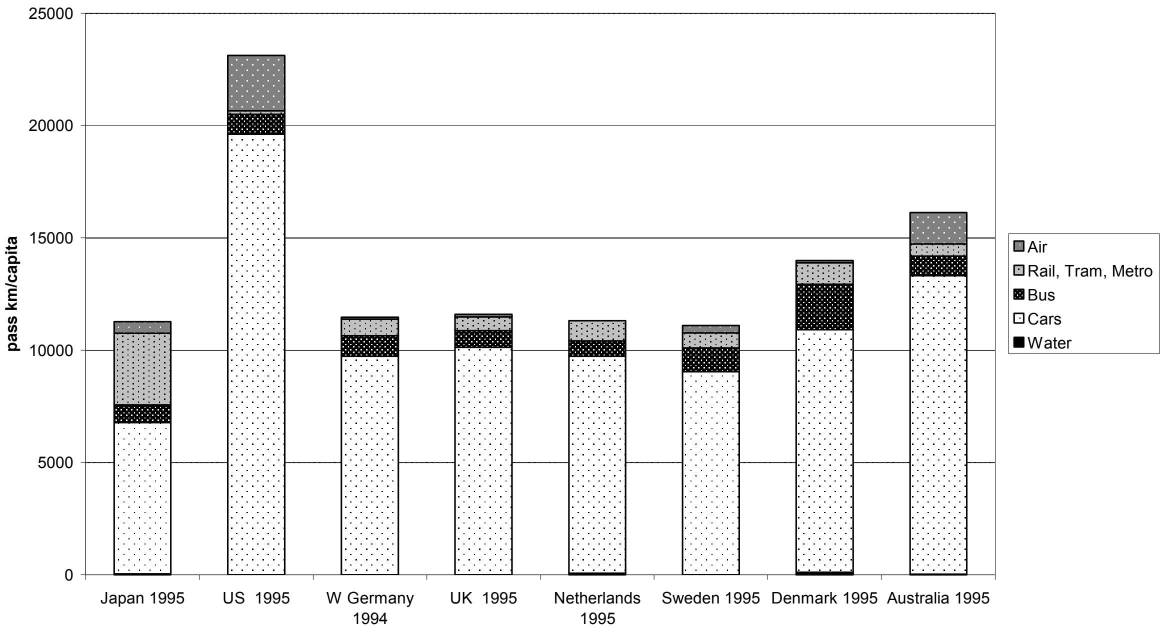
Source: LBNL and IEA

Comparison of Figures 4 and 5 shows the important contrast between car ownership and car use as indicators of car activity. While Denmark has lower car ownership than most countries (at a given GDP/capita), it has about average driving for the European countries studied. That is, Danes have fewer cars but drive them significantly more than drivers in the other European countries. This is why distance driven <u>per capita</u> is so much more important than distance driven per car to determining total fuel use and emissions. Australia and Canada, not shown, lie with the U.S., while Japan lies somewhat below Europe, for a given GDP. If estimates of non-motorised travel were included, the totals for

Denmark and the Netherlands would rise by roughly 10%, the other European countries by somewhat less, the U.S. by very little at all

Figure 6 compares per capita motorised domestic passenger transportation in the study countries in 1995 (1994 for West Germany), showing the dominance of the car. Total travel, as expressed by the distance travelled on all modes in passenger kilometres, is "driven" principally by car use. Note that automobile passenger transport is rising at a less rapid rate than car use itself because the number of people in a car (load factor) is falling: the number of passenger-km in cars grows less rapidly than the number of vehicle-km covered. Interestingly enough, European countries in the study are bunched together.[11].

Figure 6: Per Capita Motorised Passenger Transport, 1995



Source: LBNL and IEA

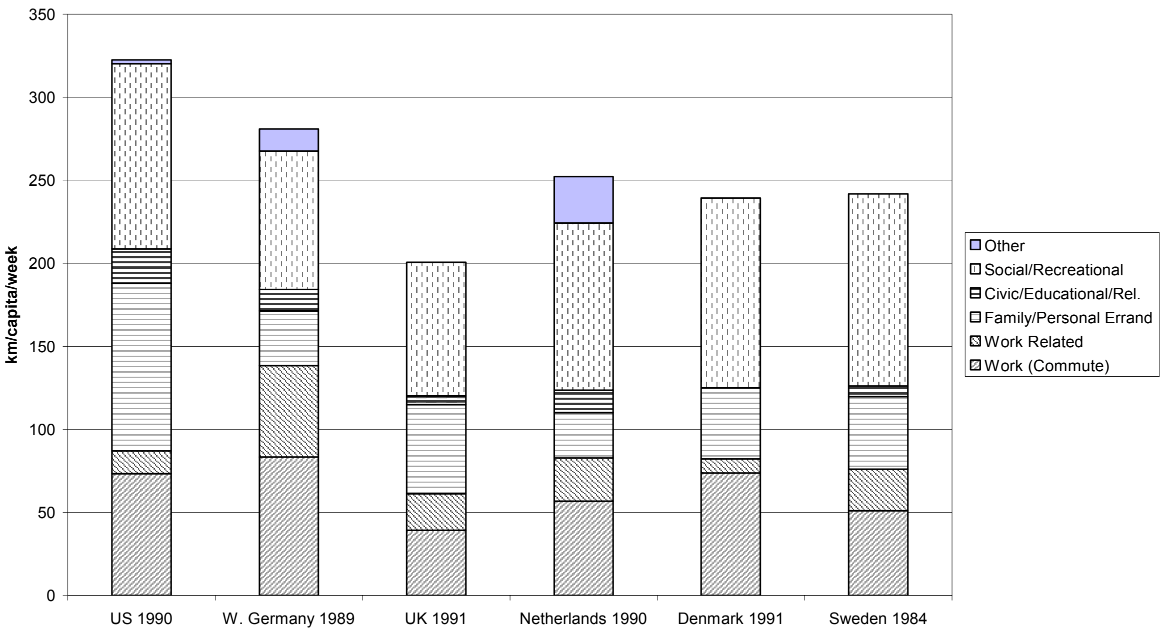
More detailed comparisons reveal characteristics of aggregate travel that are important for emissions. Overall travel per capita is far higher in the U.S. than in the other countries shown, even for a given level of GDP per capita. The U.S, Australia, and to some extent Canada (not shown) have roughly similar high levels of total travel, and the same high shares of car and air travel. This suggests that geographical factors play some role in determining total travel. By contrast, the U.K., West Germany and the Netherlands are the most densely populated countries we studied, and have lower levels of travel and car dependence. Japan is even more dense (when one considers that most people live on a fraction of the total land area there), and has even lower total travel than the European countries. Economic factors are certainly important, too, as we will note later. While there are important differences among European countries, it is nevertheless interesting how the overall pattern of travel tends to reveal these three groupings as determined by geography.

Travel patterns are an important element of the picture. The structure of travel by trip purpose, mode, and distance per trip affects fuel use and emissions because of congestion, motor performance, etc. Some results of comparing travel surveys from the U.S. and a number of European Countries are shown in Figure 7. Work travel (mostly commuting, but some trips within work) is accounting for 20-

[11] See Schipper, Gorham, and Figueroa 1995.

30% of total travel[12], services, civic, educational, and family business for about 25% (except in the U.S., where the share was higher) and leisure (including culture, sports, outdoors, etc.) for the rest. The car dominates the latter two categories, but outside of the U.S., the car accounts for only 40-60% of work trips, since these are more easily taken on collective modes. Including walking and cycling has little impact on total travel, but an important impact on total trips, since these can account for as much as 1/3 of trips. Non-work trips seem to be leading growth of car use in the U.S., probably the result of much greater saturation of trips to work by car since the 1970s (over 85% of trips, of which only 1 in 10 as a passenger). In Europe, by contrast, there is still a slow increase in the share of work trips taken in cars. People are not only moving more, but the structure of mobility, in terms of mode and purpose, is changing slowly, as our national data show.

Figure 7: Travel by Purpose



Original sources each country's personal travel survey. Australian and Japanese data non-available.
Note: US data include only 1 day travel, not longer trips, which add about 15% to the totals shown.

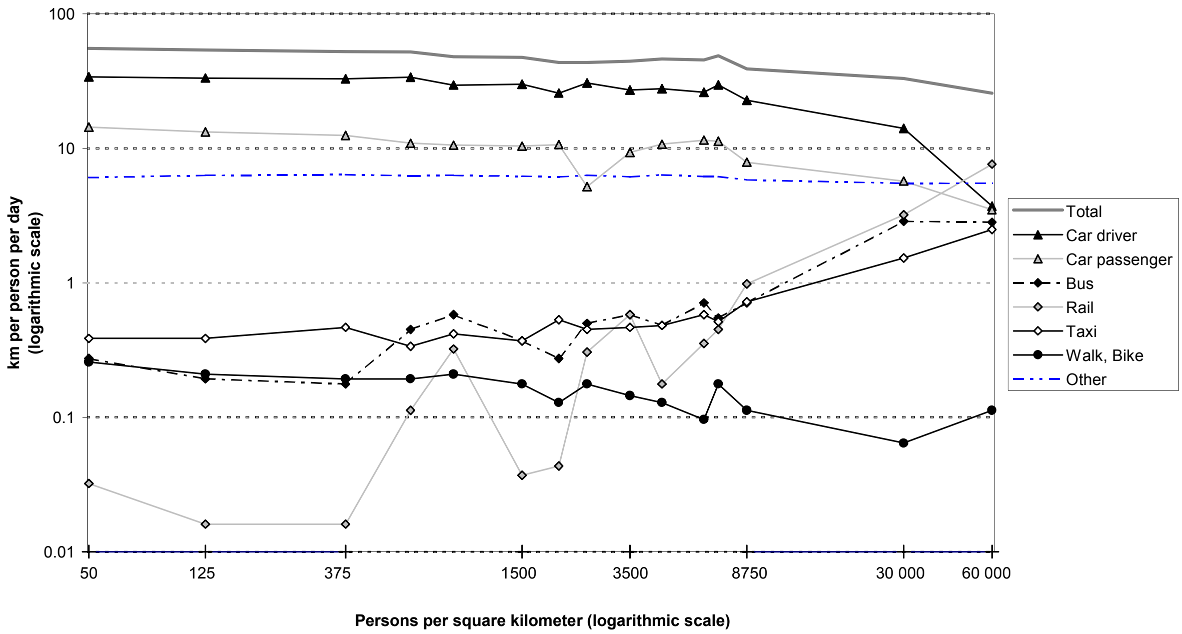
Interestingly, the average trip length in a car remains over time around 13-15 km for the U.S. and all the European countries studied. Roughly 80% of all trips are less than 20 km and 60% are less than 10 km, which implies that the car us used mostly when its engine is cold. This raises fuel use and air polluting emissions. Ironically, cars are increasingly built for higher speeds and longer trips, but they are still used predominantly for local transportation. This also means that our conclusion about the importance of country size and geography might be challenged if car trips are roughly the same length in the U.S. as they are in the Netherlands. But the longer distances in the U.S. are balanced by many shorter car trips that are taken on collective modes, walked/biked, or not taken at all in Europe.

In the aggregate, there is little doubt that the most gross variable describing urban form, population density, is related to travel. From the *U.S. Nation-wide Personal Transportation Survey*, we obtained the total travel by mode for each respondent, and, using the respondent's postal code, matched his/her residence to the population (see also Dunphy and Fischer 1994). Figure 8 shows a clear, if weak, relationship for the entire US in 1990 that holds over a wide variation in population density. Total travel falls slightly as density increases exponentially, then falls suddenly in the densest regions (New York

[12] The particularly high share of work-related trips in West Germany rises the share to 43 %

City, for example). All else equal (a dangerous assumption, admittedly), the gradual move away from dense cities should be associated with increases in travel. Conversely, higher incomes that permit greater car ownership, all else equal, certainly permit households to move away from more dense settlements where collective transport or walking serves many key purposes illustrated in Figure 4.

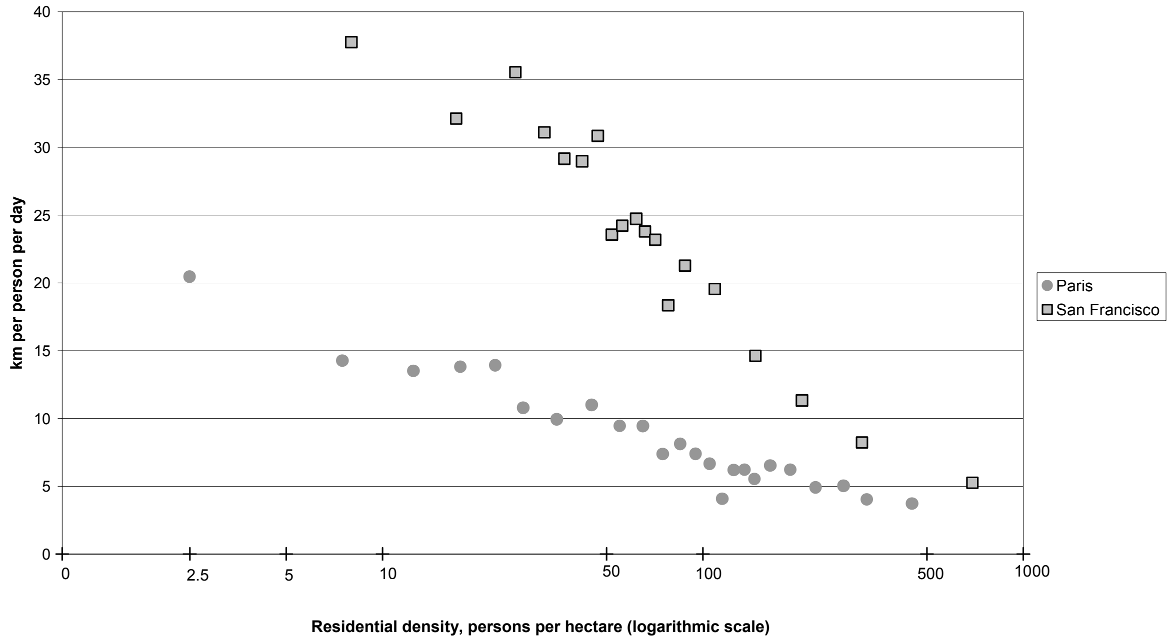
Fig. 8: U.S. Travel by mode and Residential Density



Source: U.S. Nation-wide Personal Transportation Survey

The national surveys studied did not give enough local detail to tell us how a family's surroundings might affect their travel and car use. But the interaction between urban form and travel behaviour has long been recognised as an important determinant in transportation energy use and CO_2 emissions. Are these interactions observable at the local level? Elizabeth Deakin and the late Greig Harvey (1994) obtained measures of automobile use vs. the density of where households lived in the San Francisco Bay Area. Similar data were provided by J. L. Madre and C. Gallez of INRETS, the French National Institute for Traffic Safety and Environment for the Paris (Ile de France) region (see Gallez, 1995). Figure 9 shows that the patterns of car use are similar, although the French level of travel in cars was lower. Examination of the French survey shows that for any level of income, social class, or occupational status, the same general variation of travel and cars use with density appears. Conversely, at a given population density (or distance from the centre of Paris), there are large variations in the absolute level of travel at any density according to various socio-demographic descriptors of the respondent, whether occupation or life cycle. Greening, Schipper, Davis, and Bell (1997) found this variation for U.S. families, and Schipper, Figueroa and Gorham (1995) found it in the published cross tabs of national surveys. Since family size and number of children, income, and other characteristics vary significantly from the most dense city centre out to the suburbs, this implies that some of the variation in average travel according to location is caused by the variation in the make-up of the population in each location. Thus while the drift of populations in aggregate away from the centre of large cities can be associated with greater travel, particularly in cars, only some of this increase can be directly attributed to the impact of lower residential densities alone. Still, we have identified yet another behavioural factor that has increased travel and GHG emissions.

Figure 9: Workday Auto Travel and Residential Density



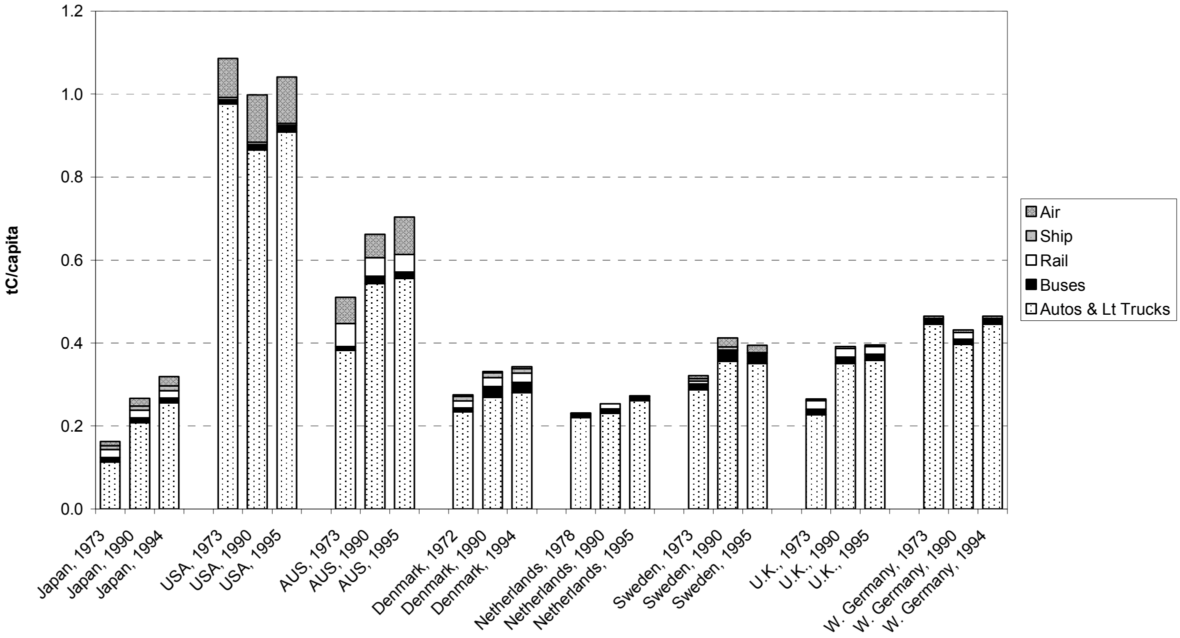
Source: University of California (Berkeley) and INRETS

Fouchier (1994) questions whether there is any particular way to describe location by density. He shows that including day-time workers among the population used to calculate "density" gives a more useful predictor of travel. Thus while urban form, however measured, certainly does affect travel and car use, it is not clear exactly how strong the relationship between form and travel really is.

Since car (and air) travel has propelled most of the growth in travel, and since these modes require more energy and emit more carbon per passenger-kilometre than bus or rail modes, energy use and CO_2 emissions have risen faster than total travel per capita. Knowing the energy use for each mode we can tabulate emissions of CO_2 in a straightforward way. Figure 10 shows these patterns (in tonnes of carbon per capita) for travel[13]. The U.S. has the highest emissions because it has both the highest level of travel (with the highest share in cars and air travel) and the highest emissions per unit of travel in cars. Japan (not shown) has low emissions principally because it has the lowest per capita travel and the largest share in rail and bus. European countries tend to cluster between these extremes, albeit more closely to Japan. We will explore details of the energy-use patterns later, but turn first to review key trends freight transport.

[13] See Schipper, 1995; Scholl, Schipper and Kiang, 1996

Figure 10: Per Capita Carbon Emissions from Passenger Travel by Mode



Source: LBNL and IEA

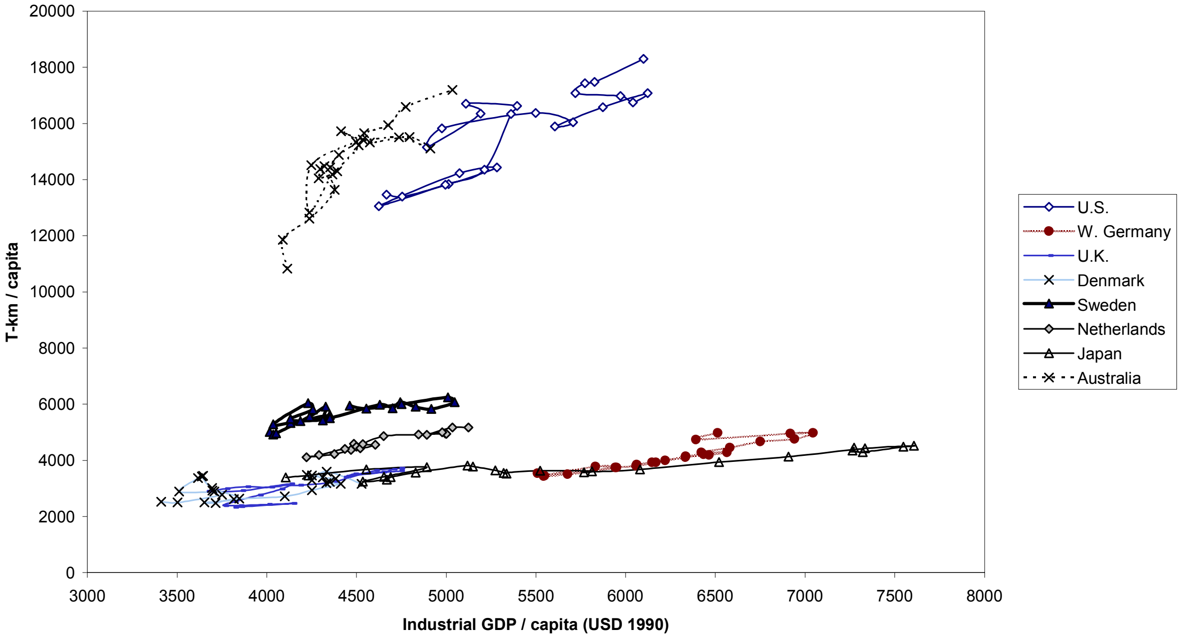
3. Freight Transport

The other part of transportation we consider is goods movement, or freight carried on the territory of each country by truck, rail, or ship and barge[14]. Activity in freight transport is usually measured in tonne-km, the number of kilometres each tonne moves. Figure 11 shows how the level of freight activity (within a country, including the domestic portion of foreign trade but excluding good carried on trucks of a third country [15]) itself is coupled to industrial GDP. Conspicuous is the wider spread among countries and the different rates of change of freight with changes in GDP. Figure 12 shows the same data by mode for 1995 (1994 for West Germany). These characteristics of freight are a key element for understanding the components of CO_2emissions.

[14] International Marine Bunkers represent 10% of world-wide CO_2 from transport (IEA, 1998). Unfortunately, tonne-km data from this branch are not available by country of origin or registry in a way that matches fuel consumption data, nor are either tonne-km or emissions "assigned" to any country. As with international air travel, we have to skip this important sector four our domestic analysis.

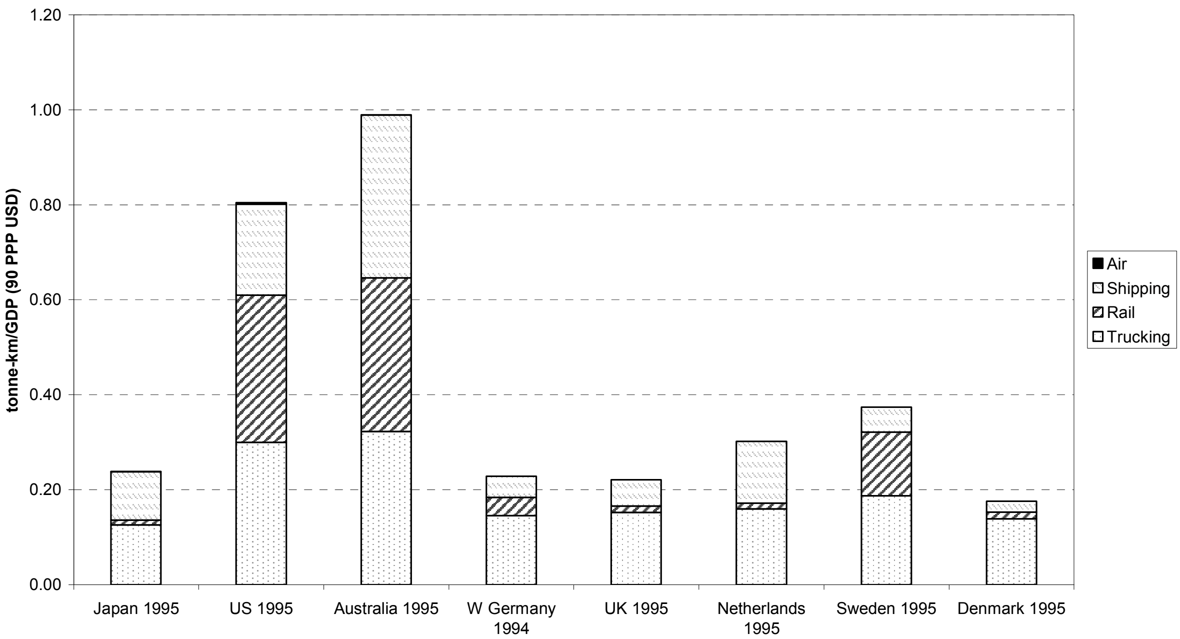
[15] At this writing we are still unable to separate transit trucking from domestic trucking in the Netherlands, which boosts that country's total freight significantly.

Figure 11: Freight Transport and Industrial GDP



Source: LBNL and IEA

Figure 12: Freight activity and total GDP

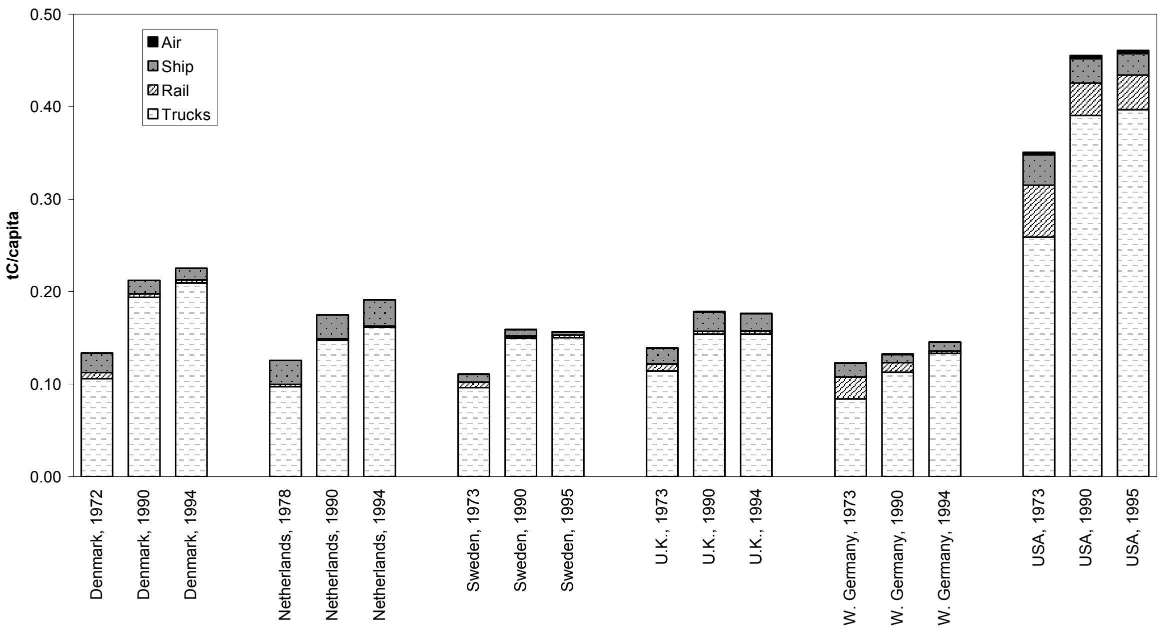


Source: LBNL and IEA

Here two factors appear major to the level of freight relative to GDP. One is geography: Australia, the U.S. and Canada (not shown), have the highest levels of domestic freight for a given GDP, clear from Figure 12. This high level is dominated by rail and shipping (barge or boat), two modes that have very low modal energy intensities. By contrast, Denmark, Germany, and the U.K. are dominated by trucking. Geography appears to work in the other direction here compared with its effect on travel: in small or dense countries, trucks more easily handle the relatively short distances freight travels. Another factor is the nature of freight hauled, conditioned by the specialisation of domestic industries.

In the large countries (as well as Sweden and Norway –not shown-), raw materials dominate freight and swell the totals because of both their bulk and the distances from point of origin (mines, forests, farms) to manufacturing and shipping points. Because of these factors, the ratio of energy use for freight to GDP for the big countries is not that much higher than that of the smaller countries. As Figure 13 shows, the CO_2 emissions patterns for freight relative to GDP are dominated by trucks. But there is greater variation in the ratio of emissions to GDP among countries than there is for travel, because both intensities and modal mix as well as the total level of freight, relative to GDP, vary so much among countries (Schipper, Scholl and Price, 1997). Germany has low emissions per unit of GDP because of low freight and low emissions per tonne-km for dominant trucks. The U.S. has low emissions per unit of freight but very high level of freight and consequently much higher emissions than Germany has. Denmark has low freight hauled per unit of GDP but a very high truck share and the highest ratio of emissions to tonne-km hauled, hence high emissions. Policies must consider each of these components to find where CO_2 restraint might occur.

Figure 13: Per Capita Carbon Emissions from Freight by mode



Source: LBNL and IEA

Components and drivers of freight activity and subsequent energy use and emissions can be highlighted: Some goods (bulk and less-valuable goods, raw materials) go mostly by rail and barge wherever possible, while smaller/lighter goods and goods with a higher value go most often by truck[16]. This mix, as well as the intrinsic distances different kinds of goods travel, and the convenience of modes, appears far more important than energy alone in determining modal shift; conversely, little modal shift is motivated just to save energy.

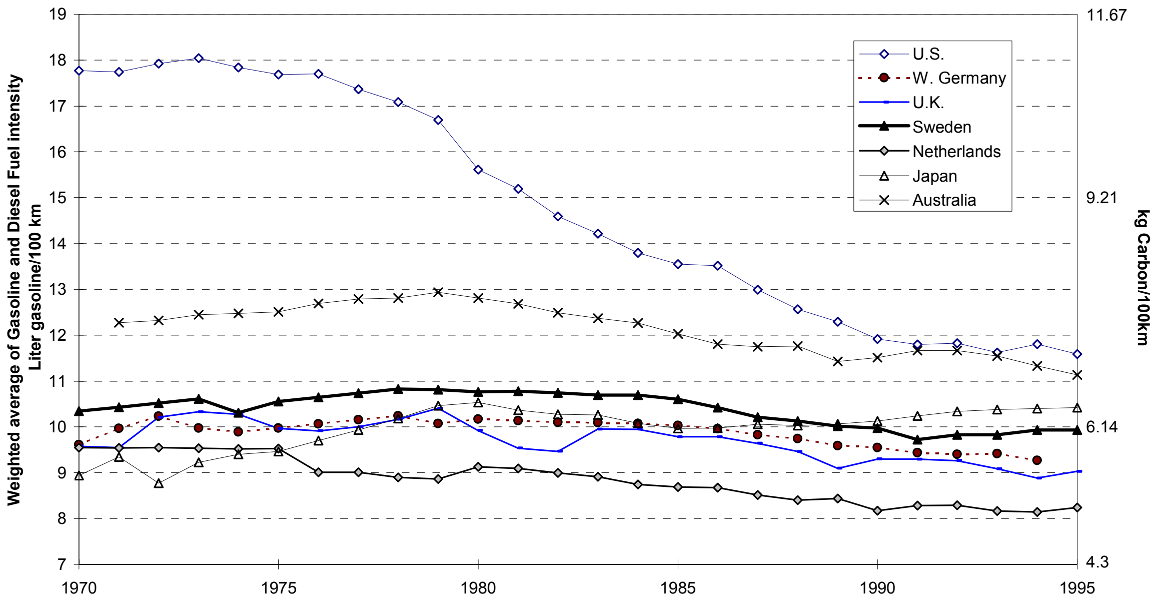
III. ENERGY USE AND CARBON EMISSIONS: A CLOSER LOOK

Emissions per capita for both passenger transportation and freight transport rose fairly steadily in almost every country studied between 1973 and 1995. The major exceptions were the U.S. (and Canada), where 1973 levels were only surpassed in the early 1990s. Moreover, the share of transportation energy use and carbon emissions in total energy use or emissions increased in every country studied. What drove these changes? Why was the U.S. trend different until recently? Answering those questions may provide some important keys to future carbon restraint.

Closer examination of trends in vehicle fuel use link activity to emissions. We defined the vehicle energy intensity as energy use per vehicle kilometre, and the modal energy intensity as energy use per tonne-km or passenger-km (c.f. Equations 1 and 2). Vehicle intensity (for a given size and power) is related to the efficiency of the vehicle, while modal intensity depends also on the number of passengers or amount of freight carried. Since cars, trucks, and air travel account for most of the energy use, we will focus on trends in the intensities of these key modes.

Figure 14 shows the average vehicle fuel intensity, or fuel use per 100 km, for car fleets. Personal light trucks are taken into account in the U.S., as they account for nearly 30% of household vehicles.[17] Fuel intensity fell dramatically in the U.S. (and Canada, not shown), but barely changed in most European countries (and in Japan). The values for the early 1990s reflect car fleets that have been almost completely renewed since the early 1970s. Approximate carbon emissions are shown on the right scale.

Figure 14: On-road Fuel intensity and Carbon intensity of Automobiles



Source: LBNL and IEA

<u>Test</u> figures for new-car fuel economy are shown in Figure 15. These reflect a modest decline in intensities among fleets in Europe, but a dramatic decline in the U.S. until the mid 1980s. By that time, the decline in new car fuel intensity and the the rising share in new “cars” of more fuel-intensive light trucks and sport-utility vehicles held the average new vehicle fuel economy constant. Bear in mind that the tests represented in Figure 15 usually understate actual on-road fuel economy[18]. Thus, the difference between the fuel-economy values in Figure 15 and those in Figure 14 are smaller than indicated. Since new car test fuel economy is hardly changing now, and fleet fuel economy is also

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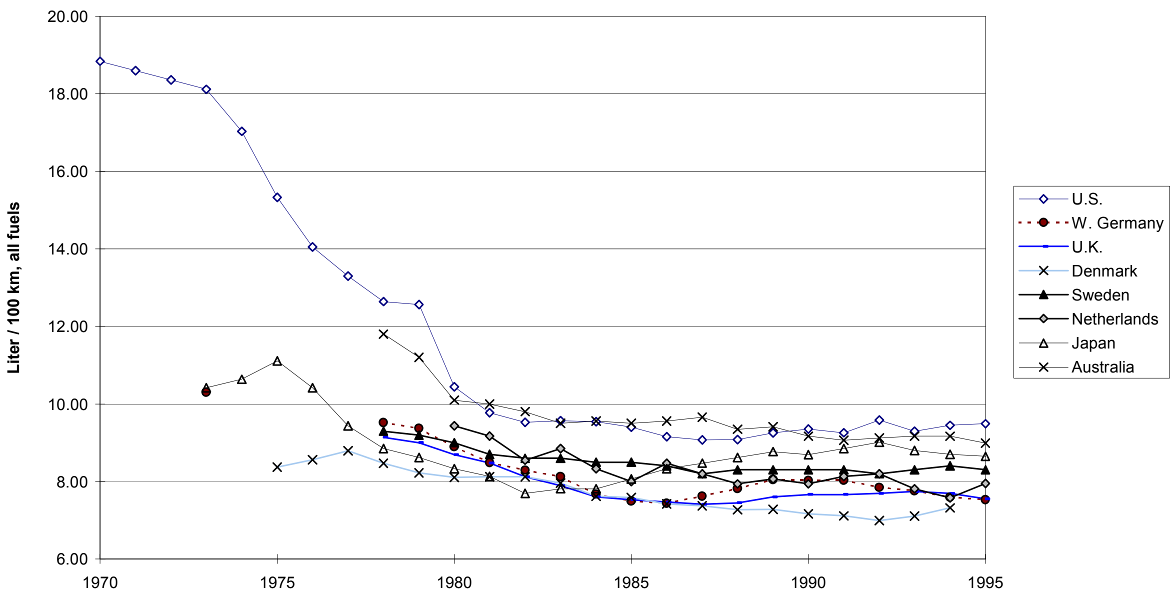
[16] See Schipper, Scholl and Price, 1996.

[17] These figures are assembled from national data (IEA 1997a) and count the energy content of each kind of fuel, which is higher for diesel than for gasoline or LPG. Results are then converted to “gasoline equivalents” at the lower heat content of gasoline of 31.4 mJ/litre. Carbon values are approximate since fuel changes affects them slightly differently than fuel.

changing only very slowly, fleet fuel economy in the countries shown must have neared a new equilibrium. Thus fuel economy in the late 1990s represents the outcome of more than 20 years of replacement of the older, less efficient vehicles with newer more efficient ones. But that process has slowed or stopped. This is of great significant for future emissions.

The lack of dramatic change in the vehicle intensities in all but the U.S. in many countries may be a surprise to many but has an explanation: Vehicle performance and weight changes have absorbed some of the savings that advance in fuel consumption technology offer. Figure 16 shows that indeed fuel use per km per unit of new car power, averaged over each year's new cars is falling steadily and uniformly in every country, and in fact differs little from one country to the others. But Figure 17 shows that power is growing steadily, propelled mainly by higher incomes. Weight is also growing, both because cars are getting larger and because extra equipment and safety measures add weight as well. Thus new technology has made cars (and most other vehicles) more efficient, but only some of the results reduced fuel intensity. Ironically, the most powerful or heaviest fleets use the least fuel per unit of power or weight, a result of economics of scale. This means that fuel intensity need not grow as fast as power or weight. There are no sign of a serious decline in fuel intensity through 1998.

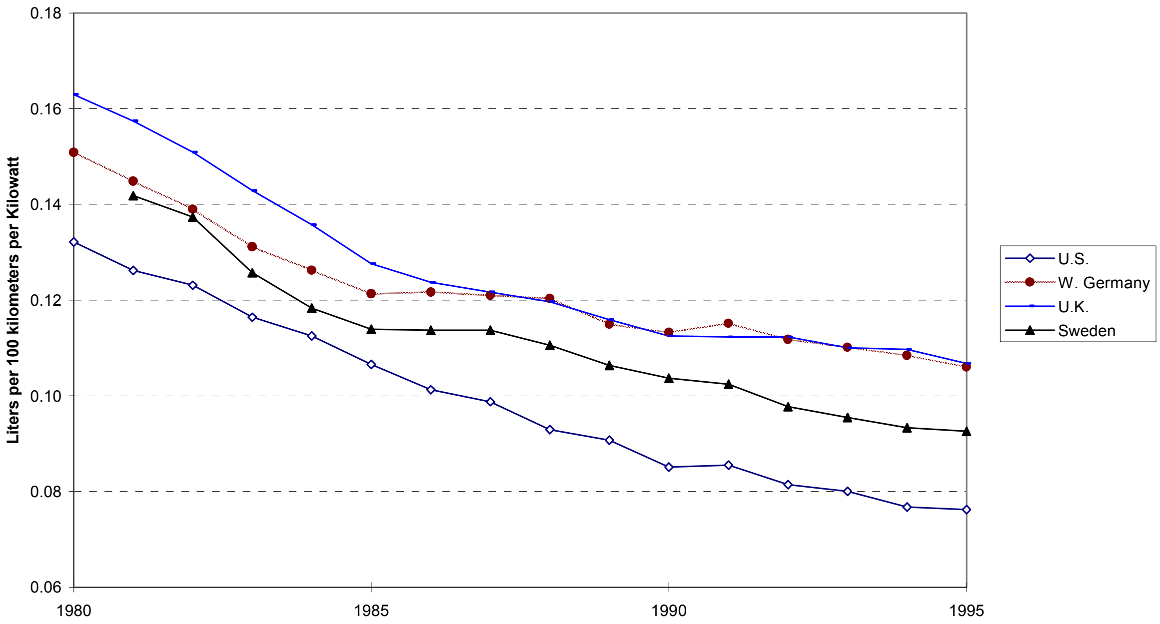
Figure 15: New Automobile Fuel Economy (tests)
1970-1995



Source: LBNL and IEA

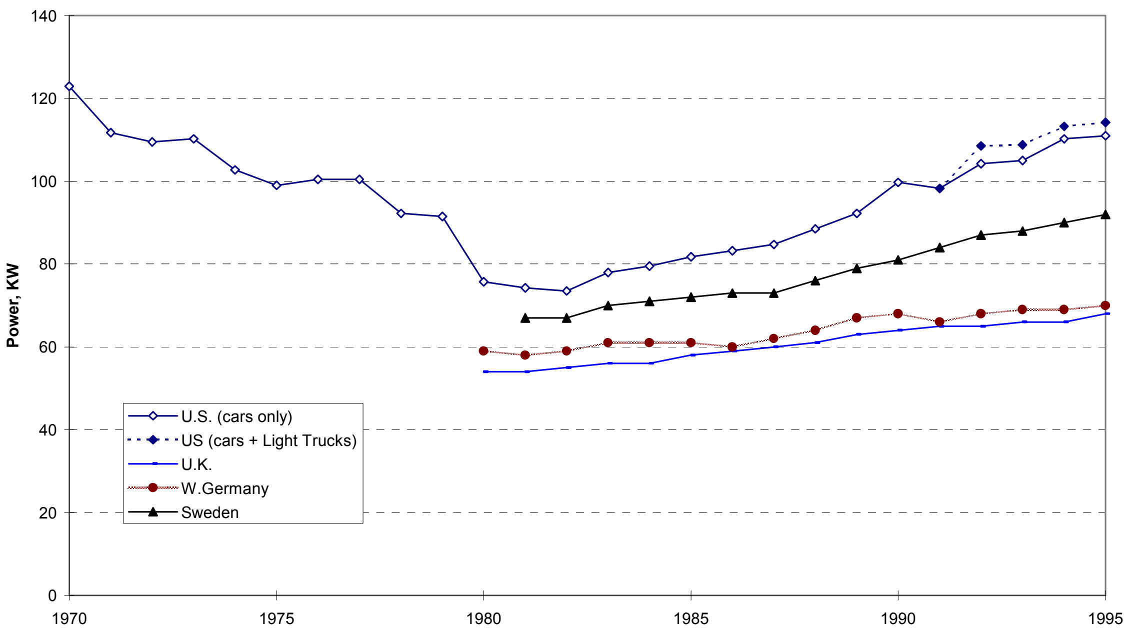
18 On that subject, see Schipper and Tax, 1994.

Figure 16: New Car Fuel Intensity
(Normalized to Engine Power)



Source: LBNL and IEA

Figure 17: Average Power of New Cars Sold (kW)



Source: LBNL and IEA

1. A Further Look at Passenger Transportation

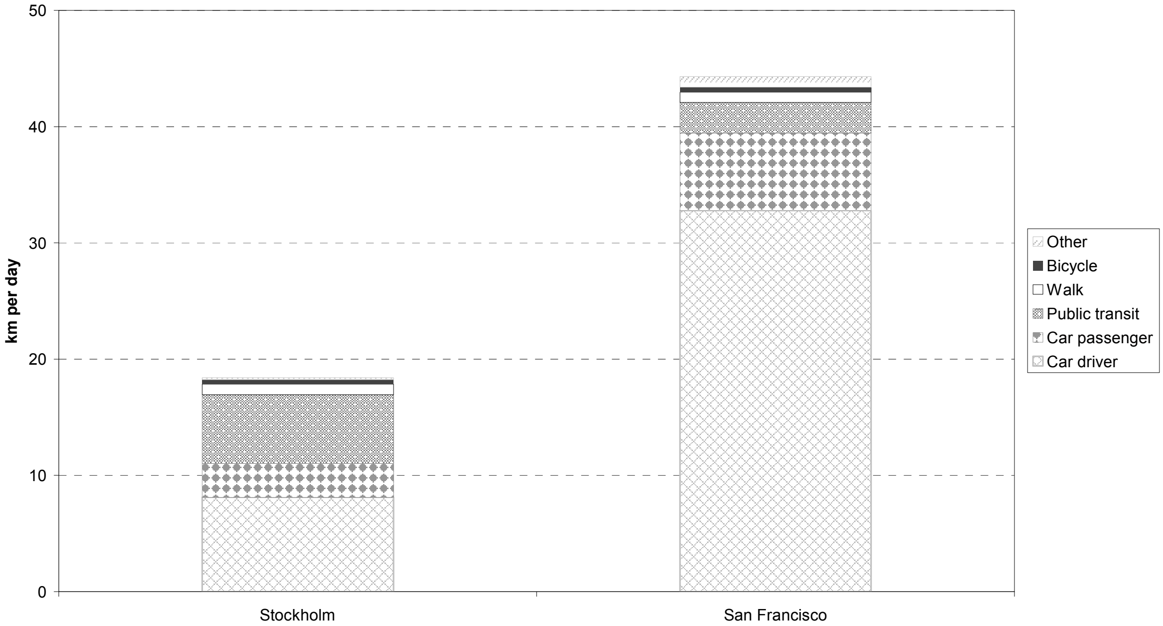
As noted previously, each year there have been fewer people per car – lower load factors -- in every IEA country. Reasons include continued drop in household size and an increase in single-person households, but also increased use of cars for commuting to and from work, particularly for women (or men as second wage-earners in families.). Since walking or biking and collective modes do have a large share of these trips in the densest areas of cities, it is not surprising if those who do drive to work are likely to do so alone, with load factors for these trips ranging from 1.1 in the U.S. to 1.3 in the Netherlands. Changes in the overall car load factor in European countries were great enough to offset the changes in vehicle intensity: it takes more energy to transport an average European or Japanese by car today than in 1973. But in North America, the vehicle intensities fell so much that the net fuel use per passenger km in cars fell by around 20%. In fact, in the U.S. today the average car and average city bus require about this amount of fuel per passenger-km, and emit about the same about of CO_2 as well.

For air travel, the modal intensities have dropped dramatically. While new aircraft consume roughly 30-40% less fuel per seat-kilometre than those that made up the fleets in the early 1970s, the percentage of seats occupied (load factor) has also risen from around 50% to over 60% for domestic routes in most IEA countries. These changes led to a drop of 50% or more in the modal intensity of air travel, to where it lies close to the value for automobiles. The U.S., with the largest average distances between domestic cities (approximately 1000 km per stage length, with similar figures for both Australia and Canada), has lower intensities then crowded Europe

We can look very closely at the link between of travel behaviour and urban form, on the one hand, and emissions on the other. Gorham (1996) compared work-day travel by neighbourhood in two metropolitan regions in detail, the San Francisco Bay Area (SFBA) and the Stockholm Metropolitan Region (SMR). Data for the Bay Area were from the Metropolitan Planning Commission's *Bay Area Travel Survey* for 1990 (the same source used by Deakin and Harvey), and those for Stockholm were from the *Resevanor Undersoekning* (1986/7), provided by the Stockholm Regional Government.

Gorham found that there does seem to be a causal relationship between urban form—specifically planned neighbourhood form, and, more importantly, regional structure—and observed travel behaviour, as revealed through household-based travel surveys. He argued that, because there has been relatively weak local and regional planning frameworks in the SFBA compared with the SMR, transportation patterns in the former reflect a significantly higher level of per capita energy use and CO_2 emissions than in the latter, even allowing for differences in urban size. Various aspects of daily trip-making behaviour in both regions were analysed, including trip-chaining behaviour, modal shares for different trip purposes, according to whether they are local or regional in nature, distance per trip, and trip duration. The nature of all these aspects of travel behaviour shows the influence of neighbourhood form and regional structure in both short-term and long-term household travel choices. Overall, Gorham found per capita travel in the SFBA about twice that in Stockholm, the difference almost totally due to travel in cars (Figure 18).

Figure 18: Weekday Travel in Stockholm and San Francisco



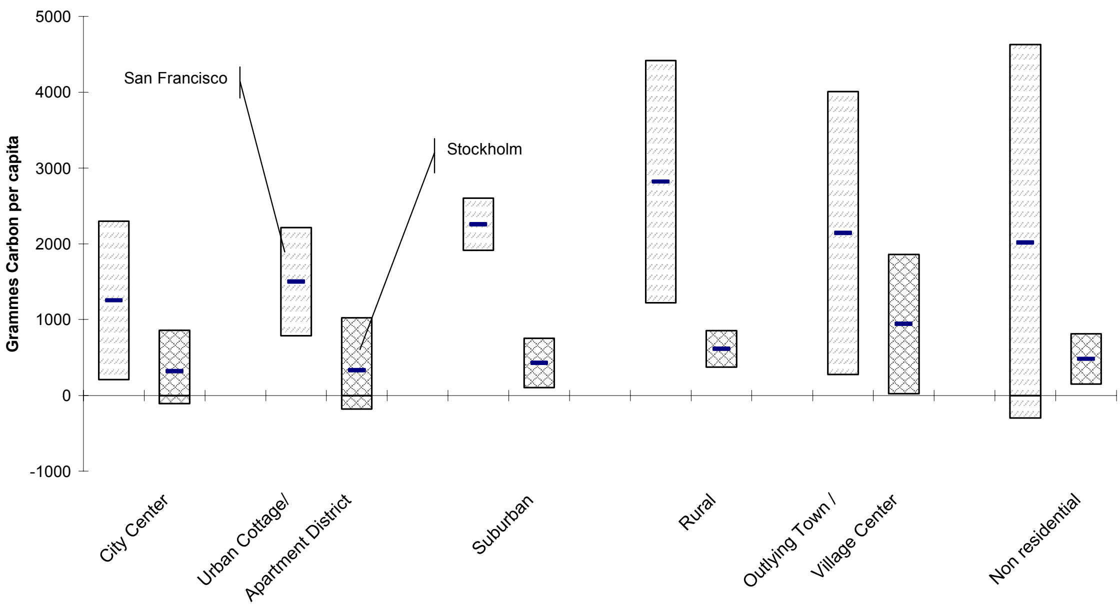
Original sources each city's personal travel survey.

When neighbourhoods are compared, the gap in travel falls somewhat, which indicates that the composition of each region contributes towards the differences in travel, a factor that may be laid to planning. The data show that the number of trips by purpose are similar between the regions, suggesting smaller differences in the purposes for which people travel than how or how far. The importance of neighbourhood can be characterised in yet another way. Examination of car trips by length shows that for each neighbourhood type, the San Franciscans make longer trips with cars. Fifty percent of the Stockholm car trips are less than 5 km, vs. 10 km for the same share of trips in SFBA. At the same time, the Stockholmers take far more short trips on other modes, including walking and cycling, than do the SFBA residents.

Finally, Gorham estimated CO_2 emissions from travel in the two cities by neighbourhood type. To do this, he converted travel by mode into carbon using national average fuel intensities for automobiles, intercity bus, and intercity-rail travel and local fuel or electricity intensities for transit and commuter rail. He used the average CO_2 emissions of the California and Swedish power systems, respectively, to impute the emissions embodied in electric transit.

Results are shown in Figure 19 as numbers with 95% confidence intervals depicted as bars. The differences are real and arise because of the overall differences in travel, the large difference in modal mix, and the importance of low-carbon electricity in Sweden. We can conclude that personal transportation in Stockholm is only 1/4 as carbon-intensive as in San Francisco, both because the actual system is only 50% as carbon intensive (per passenger-km) and because the Stockholmers travel only slightly more than half as much as do the San Franciscans. A key element of this difference is that the actual fuel intensity of car use in Sweden is only 20% below that in the U.S. In other words, the fuel efficiency of cars themselves plays only a small role in the overall difference in emissions, while the use of cars and other modes plays the dominant role. Moreover, there are significant differences in the carbon emissions from travel by neighbourhood, differences that appear to go beyond those that might be predicted by differences in the socio-demographic factors described previously. Thus we must conclude that urban form—as measured by neighbourhood type – does affect CO_2 emissions. To the extent individuals both chose where they live and directly or indirectly influence the evolution of their surroundings, we have yet another, if subtle, interaction between travel behaviour and CO_2 emissions.

Figure 19: Carbon Emissions of San Francisco and Stockholm (and 95% confidence intervals)



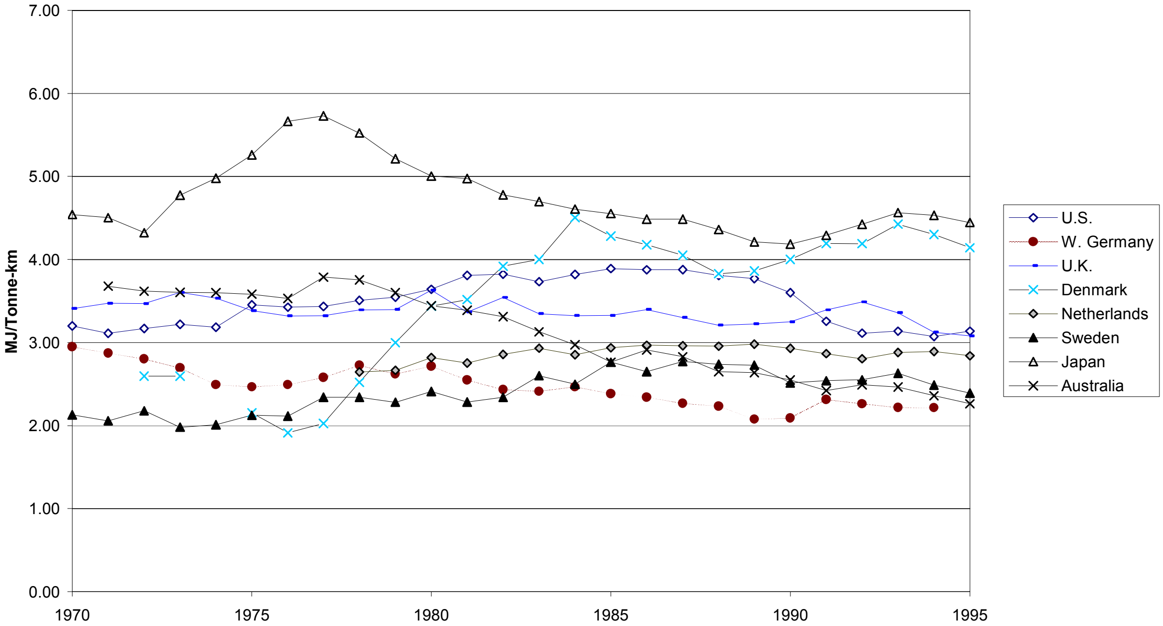
Original sources each city's personal travel survey.

2. A Further Look at Freight.

Freight presents a somewhat a different story. Schipper, Scholl and Price (1997) found that different kinds of commodities were associated with different modes of travel. Bulk materials go most often by rail or barge, but their role is declining compared with that of finished goods, which tend to travel by truck or air. While the analogy is weak, this suggests the findings of Gorham: the kinds of goods and the infrastructure are as important to the overall level of freight and modal mix as are the kinds of settlements to travel. These are factors not likely to be influenced heavily by concerns for CO_2, although fuel prices will have some impact. Thus technology and utilisation, predominantly as affect trucking, are the key parameters for understanding CO_2 emissions from freight.

In every country, the vehicle intensity of trucks of a given size fell. This was a result of increased penetration of diesels as well as improvements in a given type of diesel or gasoline truck. But the ratio of fuel use to freight hauled did not fall in all countries, and continues to vary considerably among countries, as Figure 20 shows. Since the trucks are produced by large, international firms, difference between the figures shown cannot be very much attributed to actual differences in the energy efficiency of trucks. Instead the differences arise largely because of differences in fleet mix (between large, medium, and light trucks), differences in traffic, and above all differences in the capacity utilisation of each kind of truck. These changes and differences in turn have explanations in the need for just-in-time deliveries, the rising value (as opposed to tonnage) of freight, and above all the importance of other costs besides those of fuel in determining the optimal use of trucks.

Figure 20: Trucking Activity Energy Intensities

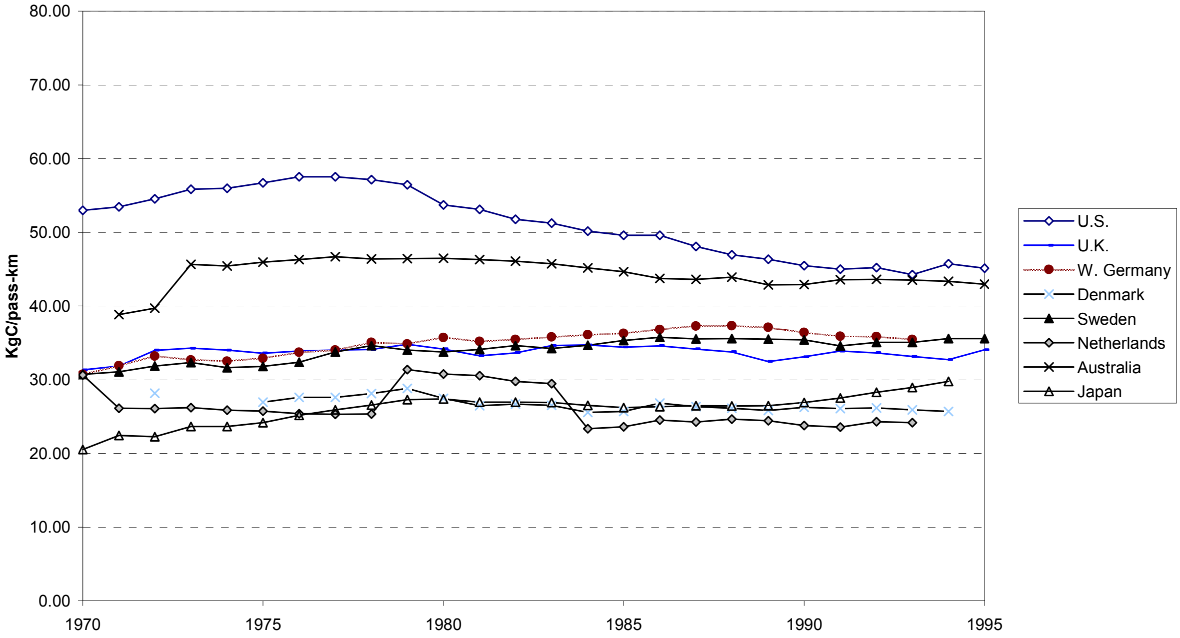


Source: LBNL and IEA

Take capacity utilisation, for example. Heavy trucks, when fully loaded (say with 40 tonnes) use about one-eighth the fuel per tonne-km as a light delivery truck carrying 200 kg. In Germany, empty running accounts for less than 30% of total km driven, while in Denmark or the Netherlands more than 45% of all truck km are empty. Thus this factor accounts for some of the great differences in the energy intensity of truck freight illustrated in Figure 20. Danish intensities were high until taxation rules were revised, starting in 1992, ending the refund truckers got for most fuel taxation. Previously the various rules provided little incentive against empty running or using trucks for other purposes. And traffic is also a factor. On the open roads of the U.S. or Sweden, traffic is much more favourable to good fuel economy than that in Germany, the Netherlands, or Japan, where intensities are second highest only to those in Denmark. Thus for trucking, it is loading and utilisation of trucks – largely non-technical factors --that affect the overall evolution of each country's freight modal intensity the most, and account for much of the difference among countries as well.

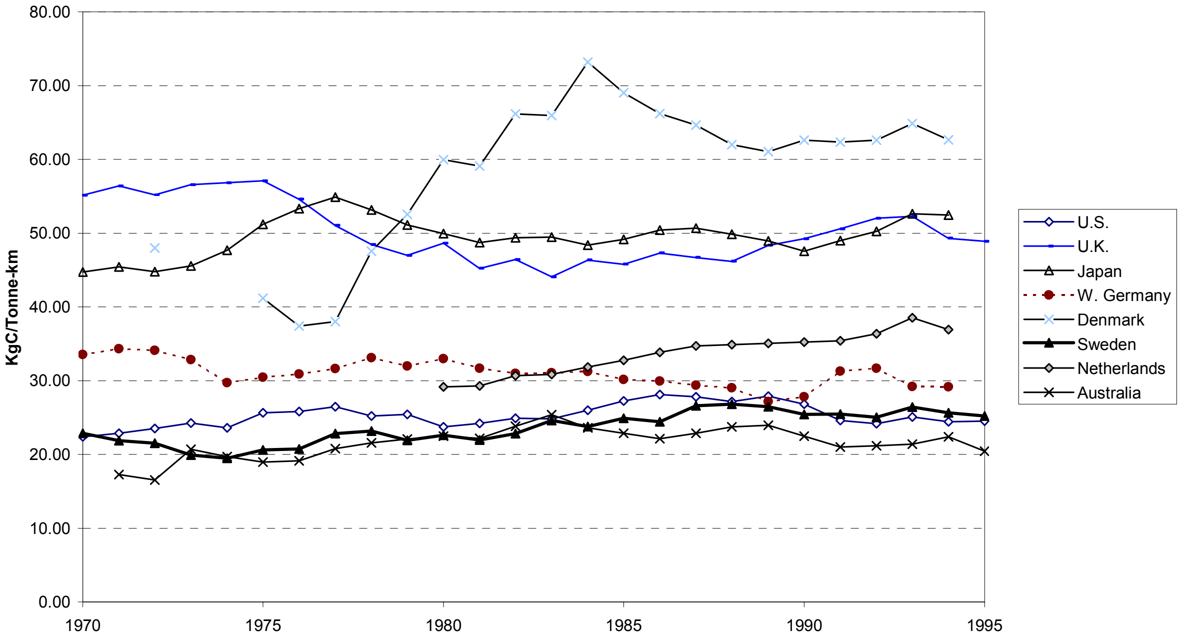
We can aggregate these results for travel and freight into two figures of merit: the aggregate emissions intensity of travel, and that of freight, i.e., ratio of emissions to passenger- or tonne-km. Figures 21 and 22 show the results, which follow energy intensity trends closely. Understanding these results improves if we use decomposition and indexing techniques for this purpose.

Figure 21: Aggregate Carbon Emissions Intensity of Travel



Source: LBNL and IEA

Figure 22: Aggregate Carbon Emissions Intensity of Freight Transport



Source: LBNL and IEA

IV. DECOMPOSING EMISSIONS

In this section we provide a decomposition of changes in emissions over time in six countries. The decomposition takes on added importance for judging how policies or technologies might overcome trends that have led to rising emissions in the past. Recall that in the decomposition reviewed here, each component represents an "all other components held constant" case. We use 1990 as the base year because of its importance to the Kyoto talks. Comparison of trends before and after 1990 offer insights into what policy-makers face in trying to hold down emissions from these sectors.

1. Decomposition of Emissions from Passenger Transportation

For passenger transportation, higher per capita travel (total **Activity**) increased emissions in every country, as Table 1, based on Laspeyres indices, shows for the group of aggregates. Modal shifts (**Structure**) towards more energy-intensive modes (cars, air) increases emissions by as much as 25% (in Japan, shown for reference), but in most countries by up to a range of 1 to 3% using the 1990 modal structure as reference.[19] This growth in activity is clearly income-driven[20]. Since car ownership is also income driven, and car ownership growth lies at the root of the modal shifts, we can say that modal shifts as well are income driven. And since modal shift itself moves people to more rapid modes and those that move them considerably longer distances (air, for example), we can say that higher incomes are associated with greater and more rapid travel.

Falling **energy Intensities** of vehicles themselves reduced emissions in more than half of the countries, but falling load factors in cars (and bus and rail in many countries) offset this restraint, leading to a net increase in energy use (and CO_2 emissions) per passenger-km in cars. Indeed, only in N. America were the emissions savings from lower modal intensities greater than 20%. Changes in Europe and Japan were small because power and weight increases offset most of the impacts of technical improvements. And in all countries, falling load factors in cars, as well as in many countries on busses and rail, also increased emissions. These factors combine to give the changes in energy intensities shown. Shifts in **Fuel mix** and utility mix (not shown separately) had almost no impact, for two reasons. First, the emissions per unit of energy released from diesel and gasoline are very close, although diesel is slightly higher.[21] Second, the role of electricity for travel (rail, trams) is so small that even the almost complete transition away from fossil fuels in some countries (Sweden, France) had only a very small impact on emissions from this sector. Combing the energy intensities and fuel factors yields **carbon intensities**. Thus by 1994/5, incomes and behavioural factors had clearly increased CO_2 emissions, even after over a decade of relatively high road fuel prices.

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[19]For Denmark the falling automobile factor led to increased emissions. We used this falling factor based on our interpretation of a number of national travel surveys. Consequently our results differ from the load factors used by Vejdirektorat, the National Road authority.

[20] See Johansson and Schipper, 1997.

[21] We are ignoring full fuel cycle emissions, i.e., emissions associated with producing, refining, and transporting fuels.

Table 1: Carbon Emissions from Passenger Transport
Average Annual Change of Impact of each "ASIF" Factor, 1973-1990, 1990-1994
Laspeyres Decomposition with 1990 as the Base Year

	EFFECTS **1973-1990**							EFFECTS **1990-1994**						
	Actual	Activity	Structure	Carbon Int	Energy Int	Fuel Mix	*GDP*	Actual	Activity	Structure	Carbon Int	Energy Int	Fuel Mix	*GDP*
Japan	3.7%	2.9%	1.0%	-0.5%	-0.4%	0.0%	3.7%	4.9%	2.3%	0.9%	1.7%	1.6%	0.0%	1.4%
Australia	2.8%	3.3%	-0.3%	-0.2%	-0.3%	0.0%	3.0%	2.1%	2.2%	1.3%	-0.7%	-0.8%	0.0%	3.3%
Denmark	1.2%	1.5%	-0.2%	-0.1%	-0.3%	0.1%	*1.3%*	1.2%	1.7%	0.0%	-0.5%	-0.5%	0.0%	*1.8%*
Sweden	1.8%	1.3%	-0.1%	0.4%	0.5%	0.0%	*1.9%*	-0.1%	-0.2%	0.1%	0.0%	0.0%	0.0%	*-0.6%*
W.Germany	2.8%	2.0%	0.2%	0.6%	0.6%	-0.1%	*2.2%*	0.0%	1.9%	0.2%	-2.2%	-2.0%	-0.2%	*1.8%*
UK	2.4%	2.7%	0.2%	-0.5%	-0.6%	0.0%	*2.0%*	-0.3%	0.0%	0.1%	-0.4%	-0.2%	-0.1%	*0.9%*
USA	0.5%	1.7%	0.0%	-1.4%	-1.4%	0.0%	*2.7%*	2.1%	1.9%	0.0%	0.2%	0.2%	0.0%	*2.3%*
The Netherlands	2.2%	2.4%	0.2%	-0.5%	-0.7%	0.2%	*2.3%*	3.6%	2.4%	-0.1%	1.3%	0.0%	1.2%	*2.3%*

Note: The Netherlands from 1981, Denmark from 1972. Int. stands for intensity.

We noted that fuel mix has almost no effect on our results. This is in part because the mix of fuels varies so little in CO_2 content. To be sure, increased use of diesel cars should reduce intensities, which should cause that factor to decline. Some of this has occurred in Germany and the Netherlands (as well as Italy and France, not examined in detail in this study). In all these countries, however, diesel is priced lower than gasoline. This advantage is utilised by those with greater than average yearly driving distances. And to some extent (Hivert 1996), those switching from gasoline to diesel increase their driving, consistent with the lower diesel price. Finally, marketing data show that for any given car model, a diesel version tends to have 10-15% more power than its gasoline counterpart, to make up for the generally lower acceleration of a diesel engine. Thus only a <u>small</u> part of the potential economy of a diesel engine is actually realised as lower fuel use and CO_2 emissions in the countries where diesel cars are popular. This digression reminds us that ultimately we have to consider terms other than the modal energy intensity **I** alone in causing changes in emissions.

Since 1990, the picture of emissions is somewhat different. Since 1990, carbon intensity fell slightly in a few countries (Denmark, France, W. Germany, and Australia). Most important, the decline from intensity changes in the U.S. has ceased. In all but two countries, the rate of growth in emissions, relative to GDP, after 1990 is higher than it was before 1990. And with recovery from recession, higher economic growth in many countries has stimulated both greater activity and slightly more rapid shift to cars and air travel. Thus since 1990, trends in emissions point away from their path before 1990.

2. Decomposition of Emissions from Freight Transport

Table 2 decomposes CO_2 emissions for freight in the same way as for travel. In all of the countries studied, actual emissions increased, and in nearly half of the countries studied, this increase was greater than that of GDP, which is shown in the last row. In a majority of countries, modal shifts (towards trucking), or **Structure**, increased emissions, often by more than was the case for travel. In contrast with travel, the modal **energy Intensities** of freight (energy/tonne-km) reduced emissions in more than half the countries. The impacts of changes in fuel mix (including fuels used to generate electricity) were again small, except where railroads underwent significant electrification and electricity was generated by low-CO_2 sources. Unlike travel, (electric) rail plays a more prominent role in carrying freight. Still, as shown in Figure 13, emissions from freight are dominated by those from trucks, so it is this mode, like cars, whose evolution is the most important for that of emissions from freight transport.

Table 2: Carbon Emissions from Freight Transport
Average Annual Change of Emissions from each ASIF Factor, 1973-1990 and 1990- 1994, Laspeyres Decomposition, 1990 Base Year

	EFFECTS **1973-1990**							EFFECTS **1990-1994**						
	Actual	Activity	Structure	Carbon Int	Energy Int	Fuel Mix	*GDP*	Actual	Activity	Structure	Carbon Int	Energy Int	Fuel Mix	*GDP*
Japan	2.0%	1.7%	1.7%	-1.2%	-1.3%	0.1%	3.7%	2.4%	-0.1%	0.6%	1.9%	1.9%	0.0%	1.4%
Australia	3.3%	2.2%	2.9%	-1.8%	-2.0%	0.2%	3.0%	0.8%	2.8%	0.3%	-2.3%	-2.2%	0.2%	3.3%
Denmark	2.8%	0.6%	0.3%	1.9%	1.9%	0.0%	*1.0%*	1.8%	0.5%	-0.1%	1.4%	1.4%	0.0%	*0.4%*
Sweden	2.5%	1.0%	0.5%	1.0%	1.2%	-0.1%	*1.9%*	0.3%	0.1%	0.8%	-0.6%	-0.7%	0.0%	*-0.6%*
W.Germany	0.7%	1.8%	0.6%	-1.6%	-1.5%	-0.2%	*2.2%*	3.2%	1.9%	0.7%	0.8%	1.9%	-1.1%	*1.8%*
UK	1.6%	2.4%	0.1%	-1.0%	-1.1%	0.1%	*2.0%*	0.1%	0.1%	0.8%	-0.7%	-0.8%	0.1%	*0.9%*
USA	2.5%	1.9%	0.8%	0.1%	0.1%	0.0%	*2.7%*	0.6%	2.9%	1.7%	-3.6%	-3.5%	0.0%	*2.3%*
The Netherlands	4.5%	2.3%	1.5%	1.1%	0.6%	0.0%	*3.5%*	3.0%	1.8%	1.3%	-0.1%	0.2%	0.0%	*3.1%*

Note. The Netherlands from 1981, Denmark from 1972. Int. stands for Intensity.

Interpreting the differences in changes before and after 1990 is difficult. This is because 1990-92 was a period of recession for many countries, with drop in freight activity that often left truck fleets carrying fewer tonnes per kilometre, i.e., lower load factors. This leads to higher intensities of freight haulage. Indeed, after 1990, emissions rose faster than GDP in a seven of twelve countries, while before 1990 the reverse was true. What is striking is that carbon intensity fell or increased by less than 0.1% per year in five countries in both periods. At the same time the structural shifts towards trucking and thus greater carbon intensity were in general stronger than the same shifts to cars and air travel.

We surmise that for freight, fuel prices have played a less important role in the overall evolution of energy use and emissions than they did for travel. The lack of a strong difference in emissions paths between the period of higher prices (which can justifiable include the years 1986-1990 when effects of new equipment were still being felt strongly through stock-turnover) and period of lower prices is thus not surprising.

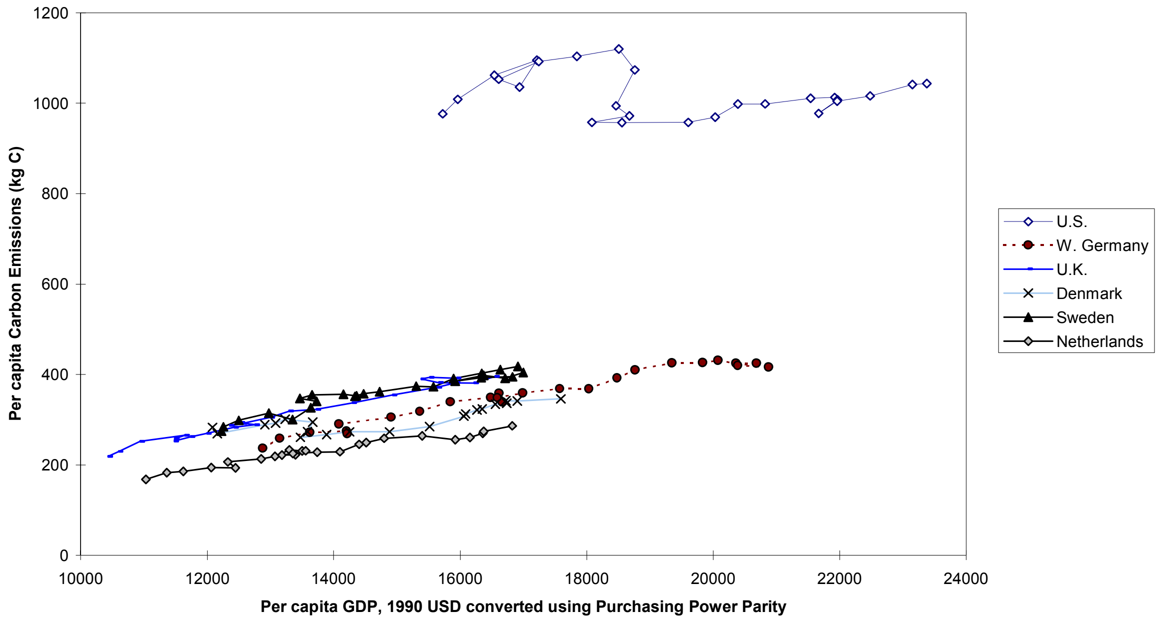
3. Summary: More Motion, More Rapidly, Raised Emissions

Changes in the amount people (and goods) travel have been the dominant cause of rising emissions. Technical factors, as the vehicle and modal energy intensities represent, led to some restraint of emissions in a few cases for cars and trucks but only gave a net reduction in per capita emissions (for travel) in one country. Behaviour and system optimisation factors (i.e., modal choices and utilisation, speed), clearly boosted emissions as well. As of 1998, there was little sign that these factors alone were abating, although their coupling to ever-rising GDP may be weakening. Measures aimed at restraining CO_2 emissions from travel and freight should focus on the underlying factors driving emissions up since 1990, as these are likely the forces which policies must circumvent. In short, the challenge is not simply to reduce emissions from a static economy, but rather reverse important trends that are raising emissions. We turn to some of those forces next.

V. THE CHALLENGES FACED: TRADITIONAL DRIVING FACTORS OF RISING INCOMES AND FUEL PRICES

The foregoing reminds us that GDP is an important factor driving both travel (cf. figures 4-5) and freight (Figure 11). Figures 23 and 24 make this connection for travel and freight-related carbon emissions. Only in the U.S. there appears to be some relenting or decoupling, both during the periods of the oil shocks (the bumps in emissions per capita at about USD 18000 per capita GDP) and a slowing of growth after that period. This trend of slowing growth (versus GDP) can be discerned in all countries, but it is not very marked at all. For freight, there is less of a clear trend in any country, in part because the ratio of carbon to freight hauled fell in more countries than it did for travel, in part because the coupling between freight hauled and GDP varies more over time and among countries. Nevertheless, our earlier suggestions that income has been the key-driving factor, are validated by these figures, and confirmed by many statistical investigations[22].

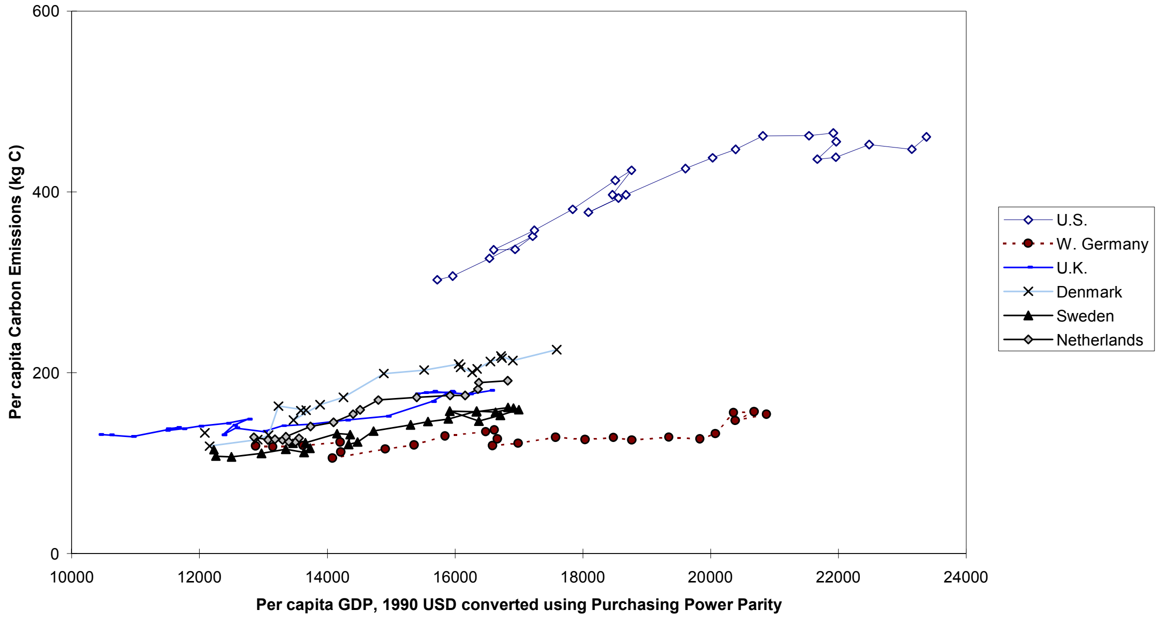
Figure 23: Per Capita GDP and Per Capita Carbon Emissions from Travel Sector



Source: LBNL and IEA

[22] See Johansson and Schipper 1997 or Thompson, Frasier and Benson 1994.

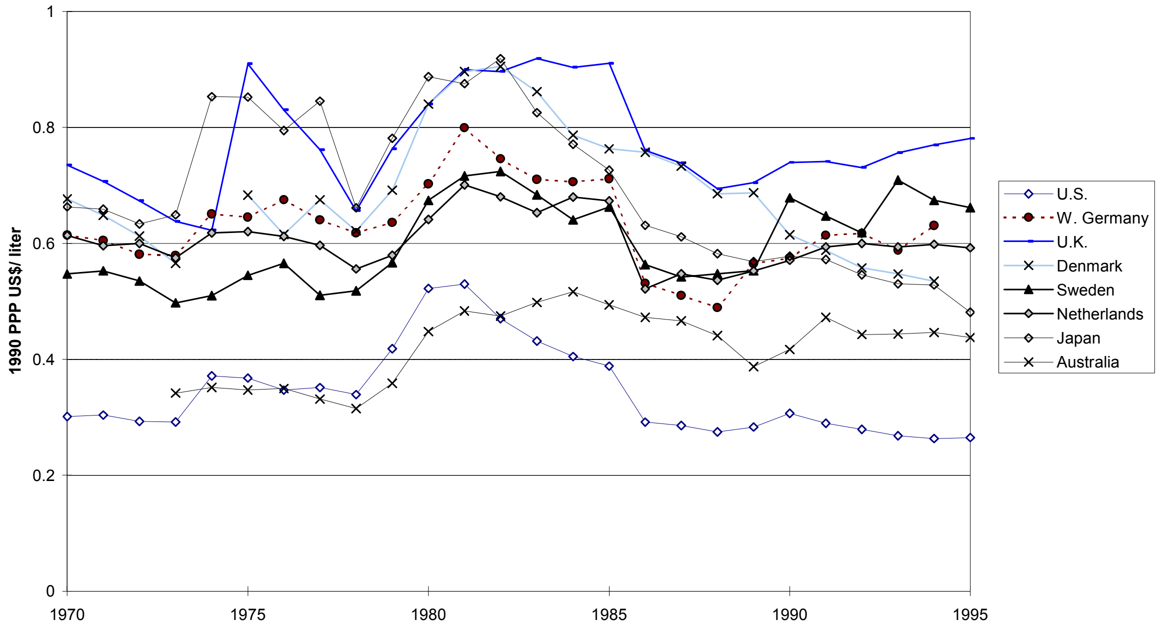
Figure 24: Per Capita GDP and Per Capita Carbon Emissions from Freight Sector



Source: LBNL and IEA

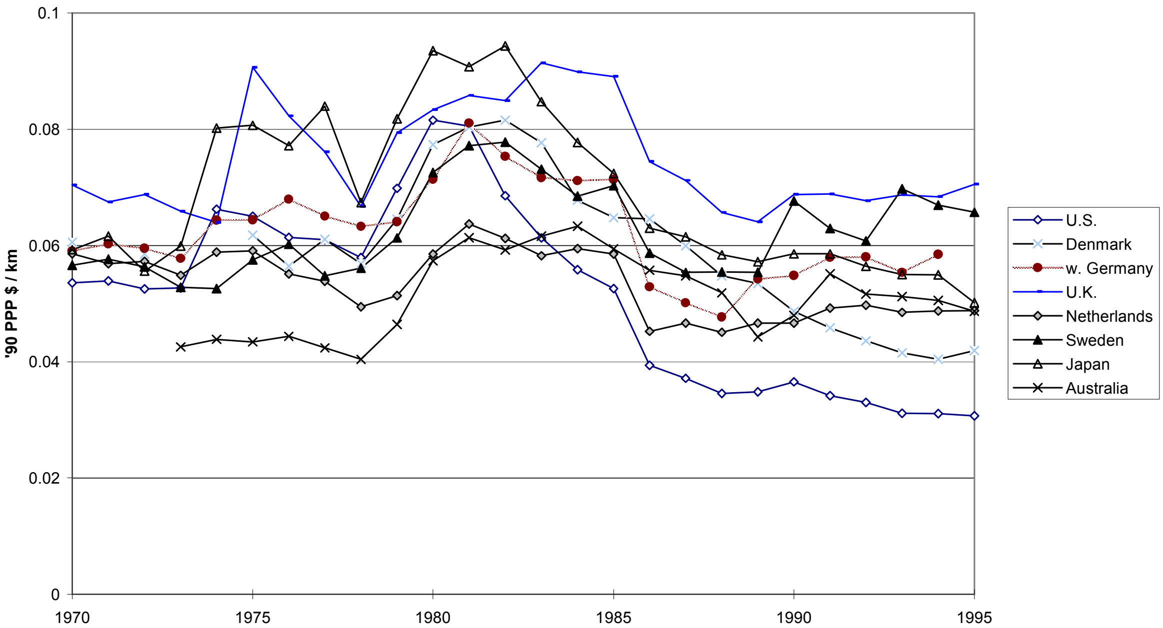
Figure 25 shows the development of average fuel prices in the countries we have studied. Diesel and LPG prices are included, weighted by their shares of total energy use for car travel in their respective countries using net heating value. What is surprising is that fuel prices in any country were higher for such a short time, and how little changed prices were in the mid 1990s from their real 1973 values. This is more dramatic in Figure 26, which shows fuel costs of driving one km. This indicator combines the effects of improved real fuel economy with that of price to estimate costs. Fuel costs of driving one km. in the U.S. in 1995 are a full 30% below what they were in 1973 and nearly 70% below their peak level of 1981.

Figure 25: Automobile Fuel Prices



Source: LBNL and IEA

Figure 26: Car Fuel cost per Kilometre



Source: LBNL and IEA

In Figure 26 there is approximately a 2.5 to 1 difference between the highest and lowest real fuel prices, as measured using purchasing power parity. In 1981 this spread was compressed to a 2 to 1 range, but got larger as U.S. prices fell in real terms with almost no new taxes making up even for the impact of inflation on taxes. The movements in Sweden, Germany, and the Netherlands from the late 1980s were principally due to higher taxes, while those in Denmark result from a purposeful lowering of taxes. No matter which perspective is taken, it is clear that few drivers in the countries studied saw real, steady price increases that left them in the mid 1990s paying more to use fuel than they did in the early 1970s.

Did higher fuel prices not affect fuel use or emissions? Johansson and Schipper (1997) report price and income elasticities of demand using a variety of models applied to a dozen of the countries studied in this work. The best estimates of the parameters are shown in Table 3.

Table 3:
Approximate range of elasticities from regressions of estimated long-run parameters, including indirect effects.
['Best guess' in brackets][a]

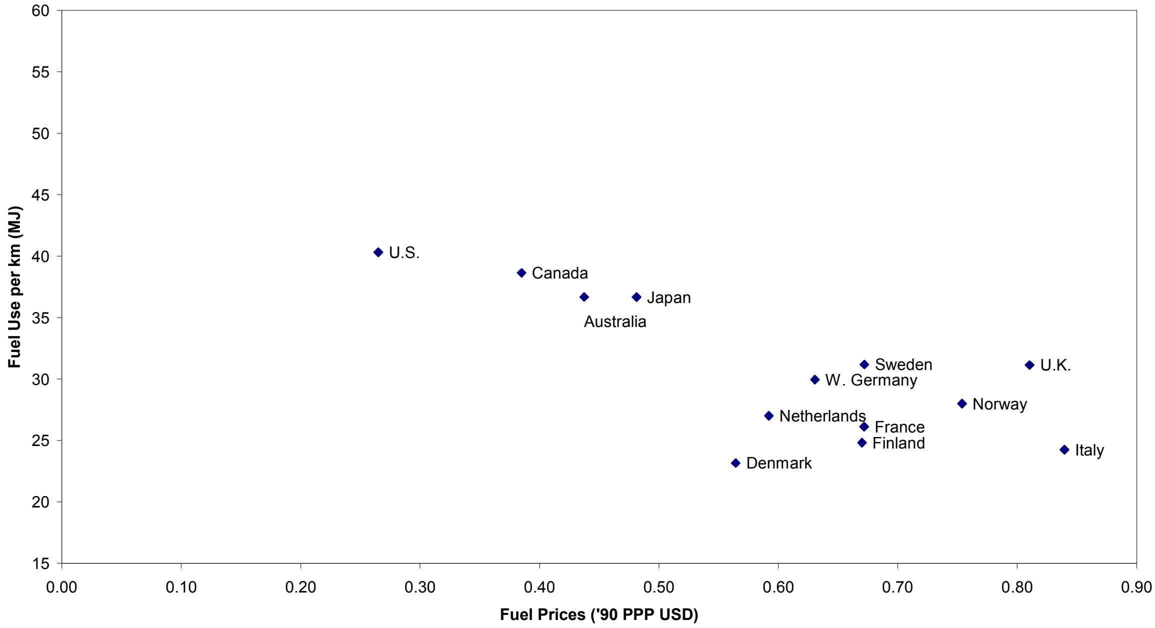
Estimated Component	*Fuel price*	*Income*	*Taxation (other than fuel)*	*Population (density)*
Car stock	-0.20 to 0.0	0.75 to 1.25	-0.08 to –0.04	-0.7 to –0.2
	[-0.1]	[1.0]	[-0.06]	[-0.4]
Mean fuel intensity	-0.45 to –0.35	-0.6 to 0.0	-0.12 to –0.10	-0.3 to –0.1
	[-0.4]	[0.0]	[-0.11]	[-0.2]
Mean driving distance	-0.35 to –0.05	-0.1 to 0.35	0.04 to 0.12	-0.75 to 0.0
(per car per year)	[-0.2]	[0.2]	[0.06]	[-0.4]
Car fuel demand	-1.0 to –0.40	0.05 to 1.6	-0.16 to –0.02	-1.75 to –0.3
	[-0.7]	[1.2]	[-0.11]	[-1.0]
Car travel demand	-0.55 to –0.05	0.65 to 1.25	-0.04 to 0.08	-1.45 to –0.2
	[-0.3]	[1.2]	[0.0]	[-0.8]

[a] What we consider as the most reasonable, on the basis of our regressions, knowledge of data limitations and statistical methods, and experiences. Thus, this 'best guess' is not based on any 'scientific' methods.

Why were the overall changes in car fuel use only dramatic in the U.S.? It is often forgotten that for most countries, real fuel prices were higher than average only for two brief periods, 1974-7 and 1979-1985, periods too short to expect radical changes in both vehicle technology and use and modal choice to occur, let alone major rearrangement of the housing and mercantile infrastructure affecting the origin and destinations of travel and freight respectively. Still, emissions per unit of GDP did fall somewhat in these periods, and emissions unit of activity fell as well. This was most dramatic in the U.S. where travel-related emissions in 1985 were at their 1973 level despite 13% more travel. Both prices and the Corporate Average Fuel Economy standards pushed new car fuel intensity downward, as Figure 15 showed. Even there, however, emissions began to rise after fuel prices dropped and new car fuel economy stagnated in the late 1980s. This was a consequence of rising numbers of drivers and entrants into the work force. In spite of the big decline in both fuel intensity and fuel prices, Americans drove about the same number of kilometres per unit of GDP in 1995 as in1973, indicating no strong "rebound" in driving as a consequence of lower driving fuel costs.

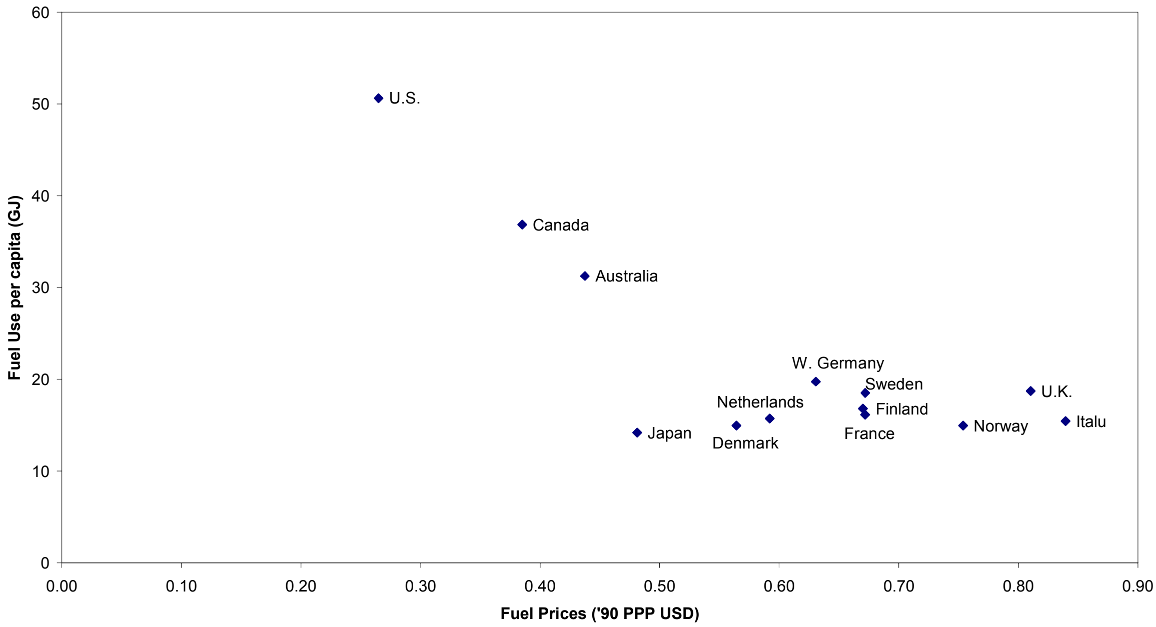
Some of the decline in car fuel intensity continued after oil prices crashed, because of the technological gains that were started in the high-price years, gains still working their way into the fleet through vehicle turnover. Yet prices seem to play a pivotal role in fuel economy or fuel use over the long run. One way to see this is to view all the countries in cross section. Figure 27, however, shows that there is a significant relationship between car fuel intensity (or per capita car fuel use) and real fuel price (with diesel included at its share of car fuel in each country). This is even more striking if we plot fuel use per capita versus the weighted price (Figure 28). If fuel use for cars in Figure 28 were normalised by GDP instead of population, the U.S. point would fall somewhat closer into the line. Interestingly, both Canada and Australia, which are included in these plots, fit nicely between the U.S. and Europe. This suggests that the U.S. is not an outlier. While we do not suggest that geography or other factors are unimportant to fuel use, the role of prices and incomes are clearly very strong.

Figure 27: Car Fuel Intensity and Fuel Prices, 1995



Source: LBNL and IEA

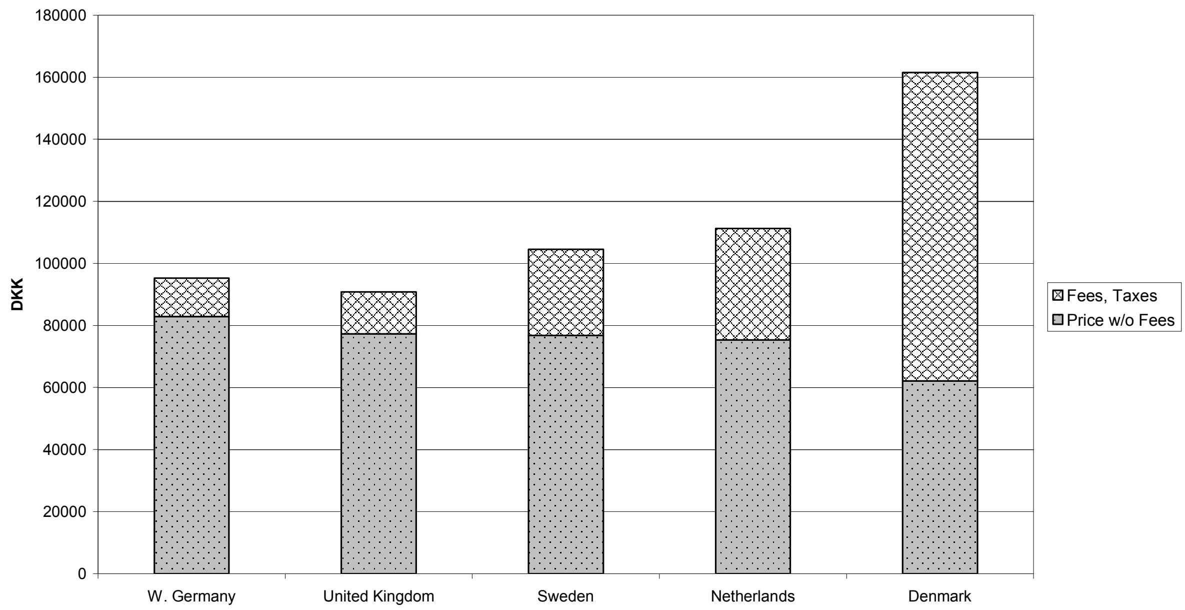
Figure 28: Per Capita Car Fuel Use and Fuel prices, 1995



Source: LBNL and IEA

The fact car fleet fuel intensities appear to be almost linearly related to fuel prices, and that U.S. vehicle fuel intensity in 1994/5 appears consistent with the points from the other countries is striking. This suggests that automobile fuel intensity is indeed a function of fuel price in the long run. But automobile efficiency in a technical sense now varies little among countries (cf. Figure 16), since cars are produced by international companies sharing largely the same technologies. Instead, it is fleet-average automobile size or weight, power (cf. Figure 17), and features that differentiate the points for fuel intensity in Figure 27. Vehicle ownership-and use-taxation, including the impact of company car taxation, certainly explain some of the scatter, since these policies affect not only the ultimate cost of fuel to the user but the cost of using the vehicle as well, which is much more significant[23]. It is not unreasonable to assert, without formal proof, that these characteristics depend on incomes (including car taxation) and fuel prices, but this formal dependence will have to be subject of future study. Nevertheless, governments do affect car prices through taxation and this has a clear affect on their characteristics and fuel use (Johansson and Schipper 1997). Figure 29 makes this point another way: Shown is the same car taxed in each of the study countries (except the U.S., where the taxes would amount to a few percent only, according to Schipper and Eriksson 1995). The large levies in Denmark reduce car ownership (evident in Figure 4), but not necessarily car use (Figure 5). They clearly force Danes to buy considerably less fuel-intensive cars than their Swedish or German neighbours (Figure 14). In this indirect way, emissions are reduced in Denmark because cars are smaller then elsewhere.

Figure 29: Cost of an Opel Astra 1.6 litre GL 3 door, 1994

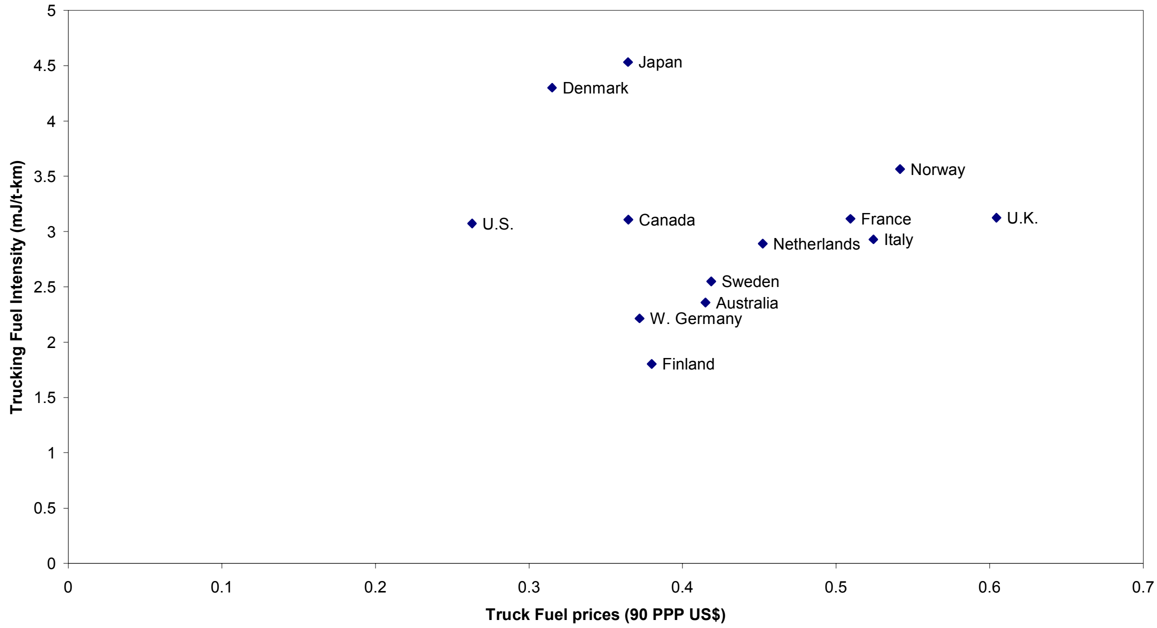


Source: Vejtransporten i tal og tekst Danish auto importers Assn, 1996

Freight presents a somewhat different picture. In contrast with cars, the correlation between trucking fuel intensity and truck fuel price is very poor (Figure 30). The correlation between the ratio of trucking energy to GDP and trucking fuel price, shown in Figure 31, suggests that trucking energy depends somewhat on price, both through modal intensity and through total volume of truck freight shipped. Thus in a cross-national comparison, prices appear to affect both fuel intensity and fuel use in most cases, but the relationships are weaker for trucking than for car use. As with cars, trucks are produced by international firms, so technologies per se play a smaller role in inter-country differences in fuel use or emissions from trucks. Instead it is non-technical factors (as noted previously), which may be less of a function of fuel prices, that differentiated countries. We do not have prices for other modes, but since they are largely untaxed and since other modes use one third to one tenth as much fuel per tonne-km as trucking, we expect fuel prices to be even less important for these modes than they are for trucking.

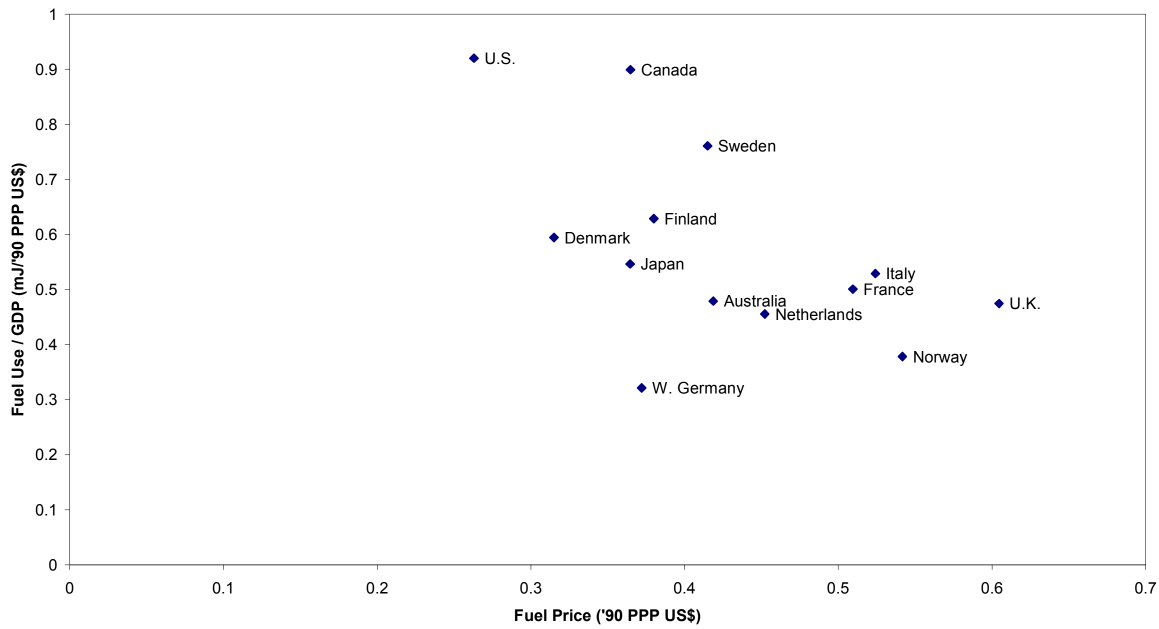
[23] See Schipper and Erickson, 1995; Schol and Smokers, 1993; NEDC, 1991; Fergeson, 1990.

Figure 30: Fuel Intensity and Fuel Prices for Trucking, 1994



Source: LBNL and IEA

Figure 31: Fuel Use per Unit of GDP and Fuel Prices for Trucking, 1994



Source: LBNL and IEA

Thus factors causing changes in CO_2 emission are intimately related to the nature of transportation -- comfort, convenience, speed. Those factors driving distance as well as modal choice are related to individual and societal choices about housing, work and leisure location. The same is true for freight. But the cost of fuel is but a small fraction of the total cost of either travel or freight, even before the cost of the transport infrastructure is considered. And the choices noted here are deeply rooted in a transportation context. This means that these choices -- today's slowly evolving transportation patterns -- may be difficult to stop simply because of CO_2 concerns. Put another way, even a stiff carbon tax would still leave the price of road fuels relatively unchanged in most countries because they are already heavily taxed. And drivers and truckers face many other costs besides those that might reflect carbon concerns. To be sure, natural limits (saturation of distance or time of travel, potential saturation of the distance physical goods are sent around) or local constraints (congestion, parking problems, local pollution) may slow or reverse some of these trends. But most national transport plans still foresee increases in personal and goods transportation with GDP without policy intervention.

It is significant nevertheless that emissions from freight, in contrast to those from travel, show restraint from lower energy intensities in roughly half of the countries studied. We speculate that this may be because structural effects on freight demand are more intense and also because freight services unlike private mobility consumption responds to business needs. Although the importance of fuel costs to total freight costs, or to the total costs of products delivered is small, there is clearly always room for saving fuel at the margin, subject to the constraints imposed by costs for equipment, labour, and maintenance. The same is true for air travel, which showed uniform and deep reductions (50-60%) in fuel use or emissions per passenger-km in all countries from both improved technology and higher load factors. In this case, however, fuel accounted for as much as 20% of operating costs and even in 1997 remains a source of cost pressure to airlines. Thus the distinction between enterprises and private automobile use may be important for explaining differences in the evolution of fuel intensities and CO_2 emissions from these different branches of transportation.

The couplings between travel or freight and GDP illustrated by Figures 10 and 13 are daunting. While there is no denying fuel prices affect this coupling through both fuel intensity and to some extent distance travelled, few expect fuel prices to change radically because of oil market changes or even taxes designed to represent the CO_2 externality itself. To some extent there may be saturation in the level of travel or freight, but no one expects either level to decline if GDP keeps rising. With that rise, then CO_2 emissions are not expected to decline. Or are they? What could cause changes is a combination of transportation policy reforms in the near term, technological changes in the longer term, and consumer/shipper responses to both forces? .

VI. THE FUTURE

What could restrain CO_2 emissions in the future? In the closing section of this review, we discuss what our research suggests.

1. Technology

Our work has <u>not</u> focused on technology. Still, there is no doubt that technology offers enormous potential for reducing CO_2 or other emissions (and many other “sins”) if asked to play a role (Michaelis et al. 1996; Peake 1997; IEA 1997c). But fuel prices have not given any strong signal towards emissions reductions; incomes are rising and people who can are moving away from congestion, noise, and air pollution, even as Japanese, N. American, and European authorities move to reduce air pollution. In early reviews we noted the importance of the interaction of technology and behaviour (Schipper, Steiner, Duerr, An, and Stroem, 1992). Trends in car size and power are one important measure of current trends in car-buying behaviour (Schipper 1995). A more recent in-depth review (Peake 1997) suggests a wide scope for improving fuel economy and reducing criteria emissions as well. Thus the problem is that technology offers promise, but that it might not be deployed to save CO_2 without market signals in that direction. Examination of automobile advertising in virtually every OECD country in 1997 confirms that this “problem” is widespread.

Alternative fuels continue to promise some relief. There are many propulsion sources that offer <u>nearly</u> the same performance as gasoline and diesel but with lower net CO_2 emissions (Sperling and Delucchi

1989; 1993; Wang and Delucchi 1992; Sperling 1994; VROM 1996b). These are making only slow progress in the market place, most likely because of the higher costs of the vehicles, but in some cases because the sources themselves are more costly than gasoline or diesel fuel. Or it is possible that "nearly" the same performance is not really correct? Again, behaviour cannot be separated from technology. Without heavy regulations or significant price differences, the alternatives are making little headway.

To be sure, diesel engines themselves offer significant potential for lower net fuel intensity and CO_2 emissions (Wester 1992). New light- and medium-sized diesel cars in Europe with Turbo-direct injection (TDI) offer fuel consumption at a steady 90 kph in the range of 3.9-4.5 l/100 km.[24] It must be remembered that diesel fuel is taxed much more lightly than gasoline in some countries; not surprisingly, its consumption is associated with significantly higher car travel. Equally as important, diesel TDI is appearing on heavier American-style vans in Europe, bringing fuel-driving costs down to affordable levels. Again, technology can work both ways when consumer behaviour is counted.

It should not be forgotten that diesel releases more CO_2 per unit of energy in combustion than gasoline, although its production may require less energy in refineries. Therefore, the net impacts of switching to diesel, or indeed any other fuel, must be evaluated using both full-fuel-cycle studies that take into account the marginal release of CO_2 anywhere in the fuel chain and studies of how diesel cars are actually used, as noted above (see also Orfeuil 1996). Particulates and oxides of nitrogen are also a concern. And the use of any propulsion source must be evaluated under realistic conditions taking into account human behaviour that affects fuel economy, not simply tests (Schipper and Tax 1994). Electric propulsion may offer attractive ways of removing combustion from cars to power plants, often released away from cities, but if that use remains untaxed as a road fuel while incentives are offered to provide easy entry to cities or low-cost parking, then consumers may again find a cheaper way to use cars than before, resulting in more driving. It is clear that alternative propulsion may offer significant CO_2 benefits at little perceived loss of driving amenity, but until we better understand all the costs, all the emissions, and above all the real interaction between alternative propulsion as a system and travel behaviour, our expectations should be at best guarded.

Reinforcing these potentials has been a flurry of announcements and activity since just before the Kyoto meeting on Climate change. Toyota brought out a hybrid vehicle, the Prius. Both Daimler and Ford invested considerable sums (hundreds of millions of dollars) in Ballard Systems, a producer of fuel cells. Virtually every company has announced both a very efficient small car and expected advances in fuel economy that will affect larger cars. While the trend towards larger and larger vehicles is still led by the U.S. market, it is clear that new ideas are now turning into new products, spurred in part by Voluntary Agreements on fuel economy within the European Union, quasi-standards promulgated by government in Japan, and the U.S. Partnership for a New Generation of Vehicles. Where these efforts ultimately lead is unknown, but they certainly portend of restraint in the growth of CO_2 emissions from light duty vehicles.

Finally, it would be unwise to rule out truly revolutionary changes. One is the hypercar concept developed by Amory Lovins (Lovins, Barnett, and Lovins 1993). Lovins foresees radical changes in every aspect of the automobile, motivated mainly by the desire to make cars less expensive to produce and use. He foresees cars that consume only 1-2 liters/100 km. Key features include direct electric drive of each wheel, a body made of carbon or a composite fibre and designed for safety and low wind resistance, and elimination of a great deal of weight related to the kinds of power plants found on conventional cars. The auto industry, bolstered in part by the US Partnership for a New Generation of Vehicles and similar programs in Europe and Japan, has taken him seriously. But no one knows which

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[7] Mitsubushi announced successful development of a TDI *gasoline* motor in September, 1996.

ideas and technologies, or which package, could emerge as a winner in the marketplace.

The other revolutionary change is that implied in the marketing strategy of Daimler Benz. Almost ready to market their small “A” class car in 1997 or 1998, they will follow this with a truly small 2-passenger “smart” car, which was exhibited at the Paris Auto Salon in 1998. This is both a gamble and a recognition of three realities: that very fuel-efficient cars with very clean emissions may soon have priority in cities (particularly in Europe and the developing countries); that the second family car market in Europe is now maturing, which could imply a market for small cars; and that the small "smart" car may well offer the first step for an affordable and acceptable car for most of the developing countries. For until now the paradigm of auto-mobility has been established by the American, and later the European and Japanese manufacturers, as a market in which car size and features keep escalating. But mobility is a valuable service that may already be too expensive for the middle class of many countries. Perhaps the “smart” car, as well as various versions of hypercars, will provide the clean, sustainable mobility for the Third World?

2. Policies Under Development

Lest the trends presented here appear to herald continuing increases in CO_2 emissions from transport, there is a positive message from this work. In each national study we reviewed (see IEA 1997b), there appears to be a combination of technological change (including that driven by Research, Development, and Demonstration projects and pricing policies), higher costs for lower-emitting fuels, and application of transportation measures that could improve transportation and restrain or even reduce CO_2 emissions over the next decade. These could change both emissions per km and total km enough to make a real break in travel fuel consumption, as clearly happened in the US in the 1970s and 1980s. For trucks, technological improvements and low-CO_2 fuels can also make a significant dent in CO_2 emissions, but it appears that there is also a very large potential for changing the way trucks are used. This utilisation may not respond radically to the CO_2 question alone, but to policies designed to increase modal competition, reduce congestion, pollution, and noise in built-up areas, lower road damage, and deal with other externalities that are focused more on freight than travel. Thus while the bad news is that CO_2 policies alone—or technologies aimed at CO_2 alone—may not have a great enough impact on emissions to reduce them, CO_2 measures implemented in close concert with transport policy measures could leave European, Japanese, and N. American transportation systems with lower total CO_2 emissions in the early part of the next century than at present.

We will not speculate here on which policies might affect these variables and therefore restrain or reduce future CO_2 emissions from travel or freight. However, our opening comments about transport externalities served to emphasise that only a broad framework that integrates concerns for CO_2 with strategies to solve other transport-related problems can be successful. If the "sins" of transport are indeed as serious as the literature suggests, then their prompt and thoughtful treatment, together with measures designed to address CO_2, including taxation, could break the links shown in the opening figures. And if governments are really as concerned both about “sustainable transport” and CO_2 emissions as their prolific reports suggest, then the forces could be mustered for this important integration.

Indeed, recent national CO_2/transport policies (UM 1991a, 1991b; Houghton 1994; Department of Transport, UK, 1996; CEC 1995a; VROM 1996b; Trafikministeriet 1997; KOMKOM 1997, see ECMT 1997 for a review) make it clear that at least in Europe, governments have linked transport CO_2 to the wider problems of transportation, rather than isolated the CO_2 problem on its own. Many of these considerations are contained in the EU Green Paper “Fair and Efficient Pricing of Transportation” (CEC 1997). This is also a course discussed in the recent US NAS study (NRC 1997), but so far, there has been no integrated transport/CO_2 policy appearing from that country. Will any of these efforts succeed? The British effort is spearheaded by local planning and steady fuel price rises; German, Danish, and Swedish authorities have introduced differentiated taxes on existing (and in some cases) new vehicles to reflect criteria emissions (ie., CO, NO_x, and HC) and indirectly CO_2, and the Danish Government has imposed yearly auto registration fees that rise with the original test fuel-consumption of each vehicle when new above a given balance point (Skatteministeriet 1996; Trafikministeriet 1997). Directly or indirectly, all of these European authorities have discussed some kinds of road pricing, but for which vehicles, and whether local and/or long-distance is unclear. The French have already introduced peak-time tolls on their Autoroute. All countries talk about raising the competitiveness of rail through privatisation, infrastructure improvements, or other means, and all countries will promote better local collective options. German car manufacturers presented their government with a pledge to reduce emissions/km in new cars by 25% by 2005, as did Volvo (VDA 1995; Volvo 1996). The French industry promised a reduction in CO_2 emissions from new cars: Renault and PSA have agreed on a target of 150 g/km by 2005 with a view to 120 g/km after that, for the fleet average of their cars sold in France. This pledge is formulated in that way to take proper account of the higher CO_2 content of a unit of energy from diesel fuel, but also opens the door to credits for electric vehicles, as Peake points out (Peake 1997). Fiat announced a pledge in an agreement with the Ministry of Environment in Italy (1997). And the CEC has won a pledges across EU (CEC 1995a; ACEA 1998). But no one in any country can more than guess what will be the ultimate package of measures, how fuel taxes will change, and how behaviour will change. A forth-coming analysis (IEA 1999) will examine key national policies more closely to see which can be expected to reduce or restrain emissions.

We noted above important feedback loops relating fuel economy and efficiency to car performance. That car size and performance are absorbing some of the benefits of new technology, rather than giving larger reductions in fuel use per kilometre, is one loop that may be hard to avoid if incomes keep growing while fuel prices stay steady or fall. This is a topic of discussion in Denmark (COWI 1995b) and is implicit in the moves to increase variable costs in Sweden the Netherlands, and the UK. as well. It is possible that if technology strikes more quickly to reduce the energy (and CO_2) costs of that performance, or if a fuel truly low in CO_2 emissions becomes available, then emissions could head downward for a long time as the new technologies appear in the market. Nevertheless, some countries, notably Denmark and Sweden, anticipate this development in their CO_2-related policy discussions and are considering higher fuel taxes to offset the lower costs of car use afforded by greater efficiency. And the possibility of saturation in driving would also tend to reduce the importance of feedback; this may explain the difference in values suggested for the U.S. and European countries noted previously.

3. Policy Implications of Our Findings

We summarise below what our work implies for the structure of future policies.

- Present trends in motorization and mobility of goods and people in wealthy OECD countries are still raising fuel use and CO_2 emissions at nearly the rate of economic growth. While there are some signs of saturation in the wealthiest countries, there is almost no break in car use, car size/features, or resulting CO_2 emissions. Nevertheless, many European countries have taken steps towards serious restraint in CO_2 emissions.

- CO_2 policies must be embedded in larger transport reform measures, as noted at the outset and codified now in the CO_2 plans of a number of European countries. Most of the measures designed to reform transport and make the system more effective will lead to somewhat lower levels of traffic, a modest rise in the role of collective modes, and less air pollution.

These all help restrain CO_2. Within this setting, CO_2 -specific measures strike hardest and show the greatest welfare benefits as well.

- Pricing is key to rearranging the various signals that boost the use of cars and trucks over other modes, encourage families to live farther from built-up areas, and permit manufacturers to look far and wide for suppliers and markets. No one expects price reforms alone to solve problems, but few expect transport problems to solve themselves without pricing reforms. This is particularly important for the possible trade-offs among pollutants, the search for fuels with lower carbon content, and the encouragement of low-pollution vehicles. So far, some of the Nordic countries have adopted differential pricing of fuels, and (with Germany and the Netherlands) have begun to tax vehicles according to their rated emissions. A new feature of this thrust is that differentiated taxation also drives yearly registration fees.
- Technology offers enormous potential for reducing environmental problems associated with transport. But pricing is also central to both developing and deploying technology. Car companies fear large investments in fuel-saving technology or alternative propulsion without strong market support for the purchases of what they develop. Subsidies for so-called "clean" alternatives will have little effect unless the "dirty" status quo is clearly marked with taxation. Even with a dramatic breakthrough in hypercars that reduces fuel consumption spectacularly, taxation reform will be necessary just to keep revenues about constant for maintaining the transport infrastructure. And while very low-consuming vehicles do not necessarily imply significant increases in vehicle use, wise governments will act to make sure that when technology leaps, signals about both CO_2 and other transportation externalities are not muted.
- There are many local policies (not explicitly reviewed here) that take direct aim at daily mobility, such as road pricing and other forms of transport demand management. Introducing such schemes is important for clearing congestion, but is often politically difficult. Similarly, there is some expectation that careful attention to land use planning and higher density development will reduce the need to travel. But the positive experience with land use planning in Nordic countries and the Netherlands is hard to relate to specific declines in car use or drops in total mobility. These tools may be wise transport planning instruments to keep cities pleasant, but they remain uncertain tools for reducing CO_2 emissions unless employed in conjunction with other measures.

The most important lesson we have learned is that packages of measures seem the strongest way to restrain CO_2 emissions. In this regard, the Danish government initiatives, which raise fuel costs, set fuel economy targets, raise the cost of buying and using high-fuel-consumption cars, close some existing loopholes in overall vehicle taxation, lower the cost of rail and bus travel, and try to strengthen local initiatives, is the most complete and nearest to passage at this writing (ECMT 1997; IEA 1997b). Similar packages under discussion in Germany (UM 1991a, 1991b; Bundestag 1996), Sweden (KOMKOM 1997), and the Netherlands (VROM 1996a) aim in the same direction, but are less complete at this writing. What all these initiatives recognise is the importance of considering both behaviour and technology, both economics and geography, and above all, having the patience to wait for change, and the ability to see that change through thoughtful follow-up.[10]

VII. WHAT IS HOLDING THINGS BACK?

What factors hinder changes in the transport system that would reduce or restrain CO_2 emissions? Clearly the price of emitting CO_2 continues to fall for most societies, and that alone is a hindrance. Incomes are rising, which makes larger cars and more car (and air) travel affordable for more people, and goods brought from greater distances and more diverse markets obtainable. To this must be added expected resistance by political and business groups, as well as individual consumers, to policies that at least in the short run will redefine costs associated with travel. Those who know their costs will likely rise are well informed and on guard.

But there are other inhibiting factors. For one thing, the motor vehicle business itself is under pressure from within (overcapacity and competition, labour strife), from regulators (clean air, fuel economy, uncertain incentives), and above all from consumers, whose future car-buying and using habits are always unclear. These problems make the vehicle manufacturers naturally conservative.

Finally, the scientific consensus over CO_2 does not translate easily into a social imperative felt by every driver or shipper. Lacking a serious drive to reduce or restrain CO_2, one cannot expect every actor in the chains we have portrayed to be focused on CO_2 restraint. That is why we argued that the most important step for CO_2 policies is to align them with those addressing more immediate transport-related problems, problems for which strong constituencies are pushing for real solutions.

Lets this appear to be yet another call for “no regrets policies” let it be clearly acknowledged that a wide range of groups oppose changes in regulations and pricing in every country trying to do so. But if successful, steps towards transport reform likely will lead in their own to restraint in CO_2 emissions. These steps could provide valuable time for robust low-CO_2 vehicles and fuels to truly cut emissions in mobile countries and limit the rise in CO_2 emissions in other countries significantly. Such policies could also lead to a truly sustainable transport system, where users pay their own way and no damage or net cost is left for future generations to deal with. If lifestyle changes that usher in saturation of mobility of goods and service further reduce the growth in transportation activity relative to incomes, restraining CO_2 emissions could be even more successful than thought. Our grandchildren will probably breath more easily, and be cooler as well.

CONCLUSIONS

We have reviewed key trends driving freight and passenger transportation in IEA countries since the early 1970s. In spite of two oil crises that affected fuel prices profoundly, the growth in underlying demand for travel and freight stayed coupled to economic activity, although some signs of saturation have appeared in the most motorised countries. Fuel intensity for cars or trucking fell significantly only in a few countries, and in no countries are these key indicators falling faster than underlying activity is rising. Consequently CO_2 emissions are rising in most countries faster than Kyoto targets imply.

The quantitative analysis has many important implications for policies aimed at carbon emissions in transport. First and foremost, we repeat that the factors raising emissions are still important and strongly coupled to economic activity: policies (and/or technologies) must work for many years to offset the continued influence of economic growth on higher emissions. Second, behavioural and managerial factors that may be politically sensitive (trucking rules, taxes on new cars) are as important as purely technological factors in driving the rise in emissions or hindering a decline. These factors have absorbed some of the technological improvements that have increased vehicle efficiency in recent years but not reduced specific emissions very much. Next, there are feedbacks between the important factors that sometimes lead to erasing some of the gains provided by technology. To be sure, the reverse is true too: factors that restrain emissions can lead to synergies that increase the emissions restraint or reduction. Finally, and by no means least, political factors that are as real as any others must be considered. Some may lie behind the impressive coupling between emissions and economic activity, others may have contributed to weakening that coupling in the past.

There is one other element that emerges from this overview: Time scales. While vehicle utilisation can change rapidly, vehicle technologies, utilisation patterns related to geography and land use, and fuel mix change only slowly, over periods of decades unless a very sharp shock occurs as did in 1979/81 with higher oil prices. Land-use itself changes even more slowly. The relatively slow and in most cases small changes illustrated in Tables 1 and 2 really reflect both the weakness of stimuli and the short period of time when one of those stimuli, fuel prices, was strong. The other side of this proposition, however, is that much potential restraint remains to be harvested, which is what we discuss in the main text of this report. In that sense, the analysis here shows ways of monitoring change and progress.

When all these factors are considered, it is reasonable to expect that present policies and technological trends will flex the historical link between rising GDP and rising carbon emissions from transportation. By 2010, European countries might emit 10% less carbon from transport than otherwise projected., i.e., without policy measures. This will be due in large part to both the voluntary agreements on new car fuel economy, modest improvements in rail and bus service that will maintain or boost slightly the market shares of these modes, and the impact of transport reforms on truck use. For the U.S., it is much more difficult to say since there are no concrete policies on the table that would either raise fuel prices, shift transport costs, or force improvements in fuel economy. Quite to the contrary, U.S. trends in car characteristics are moving in the opposite direction, with only trucking and air travel continuing to show improvements in modal energy intensities. The PNGV program still has no certain outcome, particularly if we are concerned with real fuel economy in 2010. Farther down the line, however, enormous gains are possible in the U.S. and everywhere else. But only time will tell.

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